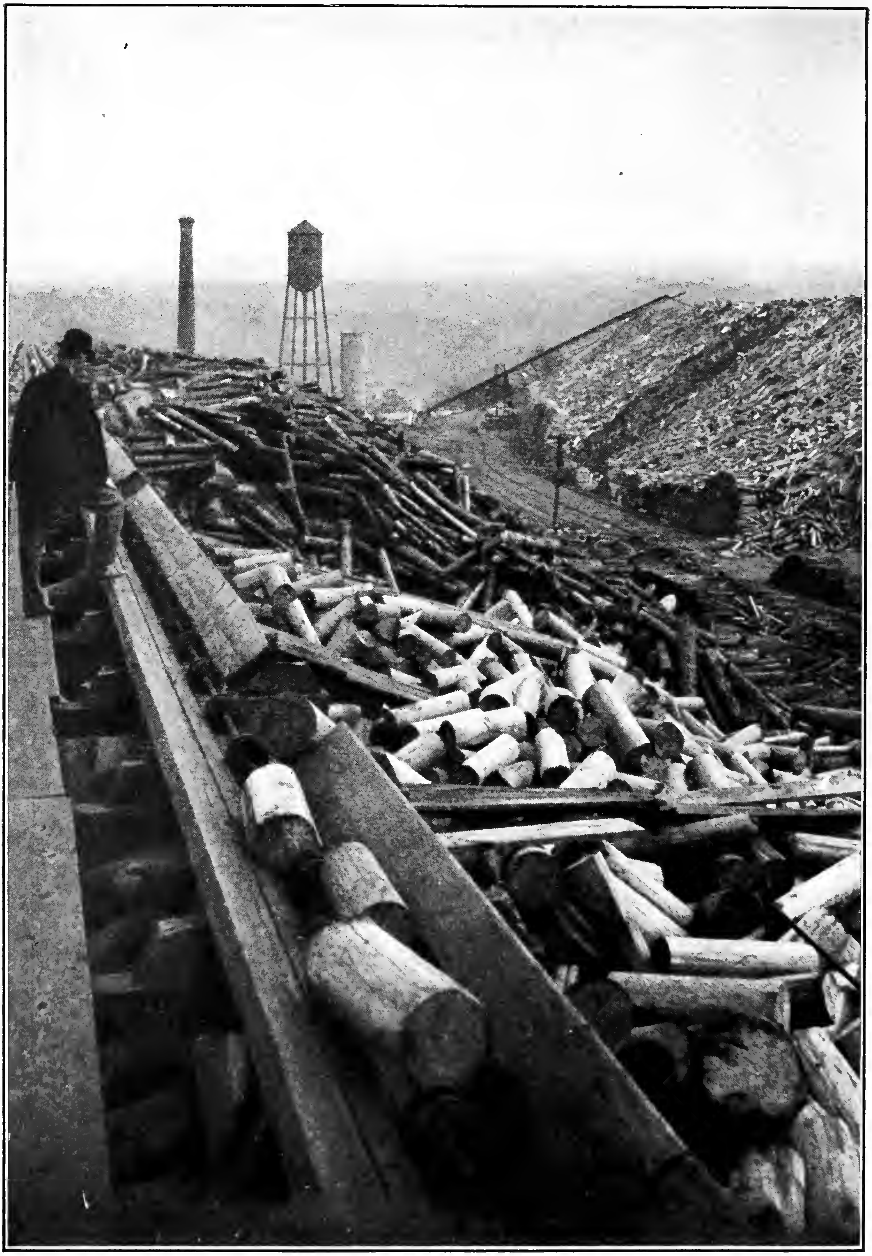

MATERIAL FOR PAPER-MAKING

An endless cable carries the blocks of wood along a chute from the sawmill. Through openings in the side of the chute the blocks are dropped at any desired point, subsequently to be transferred to the grinding-room.

Science *in the* Industrial World

BY

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CONTENTS

CONTENTS

CHAPTER IV

THE DEVELOPMENT OF THE TELEPHONE

CHAPTER V

THE EDISON PHONOGRAPH

CHAPTER VI

PRIMITIVE BOOKS

CHAPTER VII

THE PRINTING AND MAKING OF MODERN BOOKS

ILLUSTRATIONS

SCIENCE IN THE INDUSTRIAL WORLD

IN the present volume we are concerned with the application of relatively few and comparatively simple principles of science to a great variety of industries. So far as these industries can be grouped it may be said that they have to do very largely with the transmission of ideas.

We shall hear the story of the development of the telegraph, cable, and telephone, those weird, even if familiar, mechanisms through which human ideas are flashed instantaneously from one part of the globe to another.

We shall examine that even weirder mechanism, the phonograph, which embalms, as it were, and reproduces the very intonations of the human voice.

We shall outline the story of bookmaking, from the papyrus scroll of the Egyptian and the clay tablets of the Babylonians to the astoundingly multiplied output of the printing-press.

We shall learn also the story of paper-making, of the reproduction of illustrations, and of the making of those strangely realistic sun pictures called photographs, which even now seem mysterious and wonderful to the thoughtful mind despite their familiarity. The presentation of these and sundry other aspects of modern civilization, as influenced so enormously by the application of scientific ideas, makes up a volume whose content should appeal to the most practical of readers.

For the most part the industries here represented are essentially and characteristically modern. Book-making is indeed an ancient art, and paints and dyes of a crude type are manufactured even by barbarians. But telegraph, cable, telephone, and phonograph are affairs of the nineteenth century; photography is of contemporary origin; and even the older industries have undergone metamorphoses within the past generation that are all but revolutionary.

Attention has been called more than once to the extraordinary changes in the aspects of every-day civilization that industrial developments in other fields have wrought within the past half century; but nowhere else, perhaps, have there been changes so far-reaching in their influence upon international relations on the one hand and upon the details of the most modest domestic economy on the other, as those which have been effected through the application of electricity to the transmission of verbal and oral messages. Telegraph and telephone have wrought a virtual elimination of time and space, and the economic importance of this revolution is past all calculation. In telling the story of the development of these mechanisms and methods, therefore, we are obviously concerned with some of the most important of industrial problems; yet it is equally obvious that we are still in close touch with sundry departments of theoretical science but for which these practical appliances would never have been invented.

I

THE DEVELOPMENT OF THE TELEGRAPH

CURIOUSLY enough wireless telegraphy is the oldest form of communication by telegraph, as it is the most recently developed form by electrical means. As electricity was not discovered until about the beginning of the seventeenth century, however, it is obvious that the wireless telegraph used by such generals as Cyrus the Great, several centuries before the Christian era, could not have been by means of electrical apparatus.

Nevertheless Cyrus used a form of communication whereby messages were sent and received through the air, and communications made with such rapidity that in a single day a message could be sent to a distance of thirty days' journey by horsemen—more than the distance across the Persian Empire.

But Cyrus was only one of many commanders who used a system of signal telegraphy. Many generals and most nations since the beginning of history have had some such means, more or less definitely developed, for making such communication. When Napoleon was engaged upon his Russian campaign, Paris was kept constantly in touch with the movements of the French army by means of signals, except on those rather frequent occasions when fog or storm would interfere with these telegraphs.

Such telegraphing by signals, however, was only possible during clear weather, and as it frequently happened that most important messages were delayed many days by unfavorable atmospheric conditions, attempts were probably made from the earliest times to discover some means of telegraphy whereby messages could be sent with certainty in daylight or in darkness regardless of the weather.

FUNDAMENTAL DISCOVERIES

The discovery of electricity, or rather a discovery by Stephen Gray that electricity could be conducted practically unlimited distances by means of wires or threads, made possible the modern telegraph. But several discoveries as to the properties and possibilities of electricity were necessary, after Gray's initial discovery, before telegraphy in practical form was possible. The principles involved in these discoveries, such as the discovery of the principle of galvanic electricity, by Galvani, the close association between electricity and magnetism by Oersted, and the principle of electromagnetic induction by Michael Faraday, have been fully described in a preceding volume of this series dealing with the history of scientific principles, and need only be referred to here in direct connection with certain discoveries; and for full descriptions of them the reader is referred to earlier volumes of the series.

Although Stephen Gray made the discovery that communication could be made by electricity over several hundred feet of wire or cord, the thought of utilizing this discovery as a means of communication seems not to have occurred to him. His discoveries were made in 1729, but it was something like a quarter of a century later before any definite attempts were made to utilize these discoveries in telegraphy. It is probable that the idea of doing such a thing had occurred to many experimenters before that time, but if so their ideas had not been recorded; and the first proposal for employing electricity in this manner seems to have been made by a person who signed himself "C.M." in a short article which appeared in *Scots' Magazine*, Edinburgh, for Feb. 17, 1753. In this, as will be seen in the following quotation, the author had developed the idea covering the underlying principles of electric telegraphy. This communication was the following:

"Sir:—It is well known to all who are conversant in electrical experiments, that the electric power may be propagated along a small wire, from one place to another, without being sensibly abated by the length of its progress. Let, then, a set of wires, equal in number to the letters of the alphabet, be extended horizontally between two given places, parallel to one another, and each of them about an inch distant from that next to it. At every twenty yards' end, let them be fixed in glass, or jeweller's cement, to some firm body, both to prevent them from touching the earth, or any other non-electric, and from breaking by their own gravity. Let the electric gun-barrel be placed at right angles with the extremities of the wires, and about an inch below them. Also let the wires be fixed in a solid piece of glass, at six inches from the end; and let that part of them which reaches from the glass to the machine have sufficient spring and stiffness to recover its situation after having been brought in contact with the barrel. Close by the supporting glass, let a ball be suspended from every wire; and about a sixth or an eighth of an inch below the balls, place the letters of the alphabet, marked on bits of paper or any other substance that may be light enough to rise to the electrified ball; and at the same time let it be so contrived, that each of them may reassume its proper place when dropped.

"All things constructed as above, and the minute previously fixed, I begin the conversation with my distant friend in this manner: Having set the electrical machine a-going as in ordinary experiments, suppose I am to pronounce the word *Sir;* with a piece of glass, or any other *electric per se*, I strike the wire *S*, so as to bring it in contact with the barrel, then *I*, then *R*, all in the same way: and my correspondent, almost in the same instant, observes these several characters rise in order to the electrified balls at his end of the wires. Thus I spell away as long as I think fit; and my correspondent, for the sake of memory, writes the characters as they rise, and may join and read them afterwards as often as he inclines. Upon a signal given, or from choice, I stop the machine; and, taking up my pen in my turn, I write down whatever my friend at the other end strikes out.

"If anybody should think this way tiresome, let him, instead of the balls, suspend a range of bells from the roof, equal in number to the letters of the alphabet; gradually decreasing in size from the bell A to Z; and from the horizontal wires let there be another set reaching to the several bells; one, *viz.*, from the horizontal wire A to the bell A, another from the horizontal wire B to the bell B, etc. Then let him who begins the discourse bring the wires in contact with the barrel, as before; and the electrical spark, breaking on bells of different size, will inform his correspondent by the sound what wires have been touched. And thus, by some practice, they may come to understand the language of the chimes in whole words, without being put to the trouble of noting down every letter.

"The same thing may be otherwise effected. Let the balls be suspended over the characters as before, but instead of bringing the ends of the horizontal wires in contact with the barrel, let a second set reach from the electrified cake, so as to be in contact with the horizontal ones; and let it be so contrived, at the same time, that any of them may be removed from its corresponding horizontal by the slightest touch, and may bring itself again into contact when left at liberty. This may be done by the help of a small spring and slider, or twenty other methods, which the least ingenuity will discover. In this way the characters will always adhere to the balls, excepting when any one of these secondaries is removed from contact with its horizontal, and then the letter at the other end of the horizontal will immediately drop from its ball. But I mention this only by way of variety.

"Some may, perhaps, think that although the electric fire has not been observed to diminish sensibly in its progress through any length of wire that has been tried hitherto, yet as that has never exceeded some thirty or forty yards, it may be reasonably supposed that in a far greater length it would be remarkably diminished, and probably would be entirely drained off in a few miles by the surrounding air.

"To prevent this objection, and save longer argument, lay over the wires from one end to the other with a thin coat of jeweller's cement. This may be done for a trifle of additional expense, and, as it is an *electric per se*, will effectually secure any part of the fire from mixing with the atmosphere. I am, etc., C.M."

EARLY EXPERIMENTS

Following this proposal, various telegraphs were invented, most of them too complicated or too visionary to be of any possible practical importance. Galvanic electricity had not as yet been discovered and the static electricity then available was most erratic and uncertain in its action. Nevertheless by the end of the century, the time of the discovery of galvanism, such progress had been made by numerous inventors that an electric telegraph, fulfilling at least one of the essential conditions, that of being capable of transmitting definite messages, had been devised. Of the various ones that of the Spaniard, Don Francisco Salva, who announced his invention to the Academy of Science of Barcelona in December 1795, was perhaps the most important and interesting.

Salva pointed out that if double wires were laid from the city of Barcelona to Mataro, and a man at Mataro should hold the ends, he could be given a shock from a Leyden jar from the Barcelona end, and messages previously determined communicated to him. But such simple signaling would not suffice, as any telegraph to be practical must be able to send communications of every kind, and this, Salva thought, could be done with no great difficulty.

With eighteen letters every word in the language may be expressed. Thus by having eighteen or twenty wires, and a corresponding number of Leyden jars, with a man holding each jar and representing a letter of the alphabet, it would be possible to communicate definite messages to a distant city. This, of course, could be simplified, and Salva suggested that by reducing the number of men to six or even less, each man interpreting three or more signals as certain letters, definite messages could be sent.

But as even this number of wires, no matter how high they might be mounted above the ground, would be likely to be injured, Salva suggested insulating them and putting them into a single cable. He even went further than this and suggested the submarine use of the cable—probably the first suggestion of this kind recorded. In this suggestion the double wire was to be dispensed with, the water being used for the return circuit.

Shortly after the time of Salva's telegraph a Frenchman by the name of Alexandre seems to have perfected a practical telegraph which worked on the principle of an indicator that pointed to the letters marked on a dial when such letters were indicated by a similar pointer on a corresponding dial, the two being connected by wires. Alexandre, realizing the importance and possibilities of his invention, kept the method by which these mysterious indicators were made to transmit messages a closely guarded secret, although he was constantly exhibiting the practical workings of his device.

Many of the leading philosophers who witnessed these exhibitions were convinced of the practicality of this telegraph, and it is possible that had Alexandre been willing to impart his secret to certain savants who were appointed by Napoleon to examine into the merits of the inventor's claims, his telegraph would have been put to practical use. Alexandre obstinately refused to reveal his secret, however, except to the First Consul in person and alone; but his request for such an interview, in which he promised that in ten minutes he could reveal the entire secret because of its simplicity, was never granted. Napoleon was unmistakably interested, so much so in fact that he requested the great scientist, Delambre, to investigate Alexandre's telegraph and report on the matter to him. Delambre did so, and his report, although made with scientific caution, was on the whole favorable. But inasmuch as he was obliged to judge of the merit of the telegraph by casual observation of its workings, without even being allowed to know whether it was electricity or some other force that actuated the indicators of the dial, he, in his official report to the First Consul, so carefully guarded every statement that Napoleon paid no more attention to the invention.

It was a most unfortunate thing, particularly for Alexandre himself, that he was so secretive in regard to his invention. Had he made known this to Delambre, a man in whom he might have placed implicit trust, his desired interview with Napoleon would undoubtedly have been granted, and, in view of the enthusiasm and generosity of the French Emperor toward successful inventors, it is possible that Alexandre would have lived as a famous and opulent scientist, instead of an obscure, impoverished, and unhappy "crank."

GALVANISM GIVES A NEW STIMULUS TO INVENTORS

Alexandre's invention was undoubtedly made to operate by the agency of static or frictional electricity, inasmuch as galvanic electricity had only just been discovered at that time. But shortly after this the invention of the "voltaic column" gave a fresh stimulus to inventors who were attempting to perfect the telegraph. One of the first applications of this invention of Volta's was by the same Spaniard, Salva, referred to a moment ago, about 1804; but a more successful attempt was made by the Bavarian Sömmerring, who utilized with this invention the discovery of Nicholson and Carlisle that a galvanic current would decompose chemicals in solution.

It had been found by these two scientists that if two points of metal were immersed in water and connected with a galvanic cell, the water would be decomposed into its elements, oxygen and hydrogen, by the action of electricity, this decomposition being indicated by small bubbles which were given off at the two points of metal in the fluid. Streams of these bubbles appeared at these points as soon as the current was turned on, ceasing as soon as it was turned off. In other words, the closing and opening of the circuit could be detected almost instantly by observing the bubbles given off by the metal points. This discovery of the action of a galvanic current was at once utilized by Sömmerring to produce a semi-practical telegraph.

Sömmerring's first invention was made with a glass jar containing acidulated water into which protruded five metal points. Each of these points was connected with a voltaic battery by wires so arranged that when any two of them were touched with a metal handle made for the purpose, a circuit was completed and bubbles of gas were given off from the two corresponding metal points in the water. By including a certain number of wires or points, or by working a definite number in combination, messages could be sent by this chemical telegraph.

Sömmerring, continuing his experiment, finally arranged a sort of code whereby telegraphic signals could be sent and interpreted by a process considerably simplified over the original form. His simplest telegraph, however, was one in which each of the letters of the alphabet was represented by a metal point in the glass jar containing the fluid. At the base of each point the letter was marked so that it could be read instantly by the receiver. In this way a simple stream of bubbles given off by a metal point indicated that a certain letter was to be used in making up the words of the message. Such an arrangement necessitated the use of at least twenty-five wires, one practically for each letter and one extra for the return current, and was, of course, impracticable.

One of the most ingenious things about this chemical telegraph was an arrangement whereby the attention of the receiving operator could be attracted at any time. The sending operator could ring a bell of the receiving machine by simply pressing a button which closed one of the circuits for a few seconds. It was so arranged that the bubbles of gas produced at the metal point of this particular circuit accumulated under an inverted cup attached to a lever and immersed in the fluid of the receiving apparatus. The accumulation of gas naturally caused the cup to rise toward the surface, and lifting at the same time the lever, it released a small leaden ball which fell upon the alarm bell and attracted the operator's attention.

The objection to this form of telegraph, or at least the most vital objection, lay in the fact that such a great number of wires were required in its operation. These wires were arranged by Sömmerring in the form of a cable, but this of course was very expensive and difficult to repair when injured. An improvement over Sömmerring's device was what is known as Schweigger's telegraph, constructed on the same principle, but with the number of wires reduced to two. In using this telegraph a signal code was of course necessary, but this requisite was also carefully worked out by Schweigger. In actual practice, however, neither of these telegraphs was of sufficient value to make them of any commercial importance, although in the mere matter of signaling messages they were practical telegraphs.

ELECTRO-MAGNETISM GIVES NEW CLUES

In 1815, the revolutionary discovery of Oersted that a magnetic needle could be deflected by the passage of a current of electricity through a wire extended longitudinally over the needle, marked an epoch in the development of electrical telegraphy. From that moment the practical telegraph became possible, although it was two decades later before the actual working telegraph came into commercial use. In this connection it should be remembered that the telegraph as referred to here is the one in ordinary commercial use. Means of communicating and signaling at certain distances and for special purposes were employed in laboratories and in a small way by various investigators fully half a century before the perfection of the commercial telegraph. And while these early devices are interesting as recording experimental phases of the development of the modern telegraph, they must not be confused with the practical instruments finally perfected by Morse any more than the "wireless telegraph" of Cyrus the Great should be confused with the wireless telegraph of Marconi or other recent inventors.

Probably the first telegraph apparatus utilizing the discovery of Oersted was made by Baron Schilling, a Russian. While acting as an attaché to the Russian embassy at Munich, in 1810, Schilling had been much interested in one of Sömmerring's discoveries exhibited in that city. He at once began making experiments in telegraphy, and, becoming familiar with Oersted's discovery a few years later, invented a telegraph and formulated a code whereby messages could be read from a needle moving right and left as the current passed through a coil surrounding it. This telegraph, which was first made in 1825, aroused great popular interest, and Schilling received the support of some of the leading men of Russia, including Czar Nicholas himself.

One of Schilling's models of his telegraph is still in existence in Russia, this particular one having, in place of a single needle, five needles worked by five wires. It was this or a similar instrument, which the inventor, encouraged and assisted by the great men of Russia, had brought to a stage of almost practical perfection when the experiments were cut short by his death. A vital defect in his system of telegraphy was the fact that the action of the current upon the needle at any very great distance was weak and uncertain.

But while Schilling, utilizing the great discovery of Oersted, was still experimenting with his telegraph, Michael Faraday had made the equally important discovery of electromagnetic induction. By this discovery, which was made in 1831, it was found that a piece of iron could be made into a magnet by winding a coil of insulated wire about it, and passing a current of electricity through the coil. The magnetization could be produced instantaneously by closing the circuit, and destroyed with equal rapidity by breaking it. The power of such a magnet was practically unlimited, the number of coils about the iron proportionately increasing the strength of the magnet.

The study of these electromagnets was taken up by Prof. Joseph Henry in America, who succeeded in producing some remarkable magnets of this type. One of these which he made in 1833 is still in the possession of Yale University. It weighs about one hundred pounds, and was capable of sustaining a weight of thirty-five hundred pounds. Professor Henry was in the habit of giving in his class-room and at lectures some extremely interesting demonstrations of the power of his magnets. One of these was to suspend an electromagnet, connected with an apparatus whereby the current of electricity in the surrounding coils could be rapidly turned on and off, from a frame. A heavy weight of iron, ranging from twenty-five pounds upward, was then attached and held in place on the under surface of the magnet. By setting in motion the apparatus for rapidly making and breaking the current, this heavy iron weight was made to perform a series of rebounds against the magnet with a force and sound of a trip-hammer, or of rapid hammering on an anvil.

The simple explanation of this astonishing exhibition was that two forces, gravitation and magnetism, acted alternately upon the iron weight. Gravity caused it to fall when the current was broken, but before it could fall far enough to be beyond the controlling power of the magnet, the circuit would be again closed, causing the weight to fly back against the core of the magnet.

THE FIRST PRACTICAL TELEGRAPH SYSTEM

This discovery of the electromagnet was at once seized upon by inventors interested in the telegraph as the most probable means by which the invention might be perfected, and within two years after Faraday's great discovery a practical working telegraph, the first that may properly be so termed, was invented by two Germans, Gauss and Weber, of Göttingen. In this telegraph the principle of Schilling's deflecting needle was combined with Faraday's principle of the electromagnet. The signal and receiving stations were connected by two lines of wires, and as early as 1833 the two German experimenters were using this telegraph as a means of sending messages.

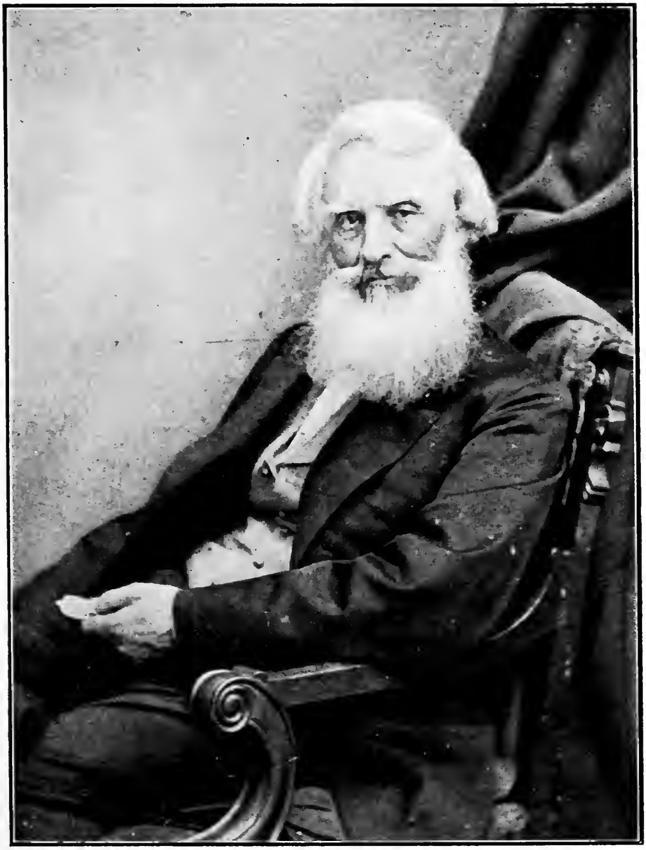
As this first telegraph had been constructed for scientific rather than commercial purposes, the two inventors requested the assistance of Professor Steinheil of Munich in developing their discovery into practical form. This was done in a most ingenious manner, the result being a really very practical instrument for both sending and receiving messages; but in the meantime the problem had been solved in a much more simple and practical form in America by the man who must go down in history as the real father of telegraphy, Samuel F. B. Morse, the artist-inventor.

The history of the attitude taken by his native country toward Samuel Morse affords at least one opportunity to refute the old proverb that "a prophet is not without honor save only in his own country." For after England had refused even to grant patents on Morse's invention, and France had first granted such patents and then appropriated them without remuneration to the inventor, while Russia and Germany turned a cold shoulder to the young American, his own country heaped wealth and honor upon him—not, however, until he had toiled and suffered long.

ANTECEDENTS AND EARLY EXPERIMENTS OF MORSE

Morse was born at Charlestown, Massachusetts, on the 27th of April, 1791. As a boy his tastes were for things artistic rather than scientific, and after attending Yale College for a time he became the pupil of Washington Allston, at that time one of the leading American painters. In company with his teacher he went to Europe to study art in the schools and become familiar with the work of the old masters. In his work he obtained considerable success as a student, and his prospects for a successful career as a painter were unusually bright.

On his return to America, in 1815, his enthusiasm for art was somewhat dampened by his failure to obtain several important commissions for historical paintings, and after working at portrait painting for several years in Charleston, South Carolina, Washington, and Albany, he finally took up his residence in New York, where, in 1825, he laid the foundation and became the first president of the National Academy of Design. Two years later he became interested in the study of electricity, dividing his time between the study of art and investigation of electricity. For a time, however, his interest in science did not replace his devotion to the brush; but in 1832, after returning from a trip to Europe undertaken with a view to further study of the old masters, his ardor for art, at least as a practical means



SAMUEL F. B. MORSE.

of earning a livelihood, was given its quietus by a refusal of the government to allow him to paint one of the great historical paintings for the rotunda of the Capitol at Washington. From that moment he turned his attention and his ambitions to the study of science, using art only as a means of furthering this end.

It was on board the ship *Sully*, returning from his European trip, in 1832, that Morse first expressed the idea that the electric telegraph was a practical possibility. The discoveries of Faraday of the year before had aroused a general interest in the subject of electricity and particularly that of electrical communication by telegraph. A fellow passenger of Morse's on board the *Sully* was a certain Doctor Jackson, who was much interested in the possibilities of electricity and magnetism. During many conversations and discussions with his fellow passengers on the trip, Morse expressed his belief that it would be possible to produce a telegraph by which, through the simple process of making and breaking a current along the wire, a code of signals representing the alphabet could be devised and turned to practical account. He not only expressed this belief but made sketches of electrical apparatus illustrating the principle upon which a telegraph might be successfully constructed.

On reaching New York he began a series of experiments to carry out the ideas formed on shipboard. For four years he continued these studies, struggling in poverty and sometimes in actual want of food and clothing. By 1835 he had constructed a fairly successful telegraph, and had formulated a practical code for signaling and receiving messages. In these experiments, however, the distances to which messages could be sent were limited, and for a year this limitation proved a stumbling-block, but in 1836 he invented his system of "relays" for reinforcing the current at intervals along the line and overcoming the difficulty.

On the second of September, of the year following (1837), Morse gave his first exhibition of the fruits of five years of labor and privation. In his little room in the old University building in New York he had constructed a circuit of about seventeen hundred feet of copper wire arranged with sending and receiving instruments and relays. To this room he invited a few of his intimate friends and there gave a practical exhibition of sending and receiving messages. The enthusiasm created by this demonstration led almost immediately to a proposition from the firm of Vail & Co., metal workers in New Jersey, who shortly after became associated with Morse in promoting and developing his telegraph.

Patents were granted by the United States in 1837, but no action being taken at once by Congress on a petition which Morse made asking for an appropriation of funds to defray the expenses of testing the practicality of his invention, he sailed for Europe. It was while on this trip that England refused to grant him patents, and the other countries of Europe showed their indifference. Returning to America, therefore, Morse renewed his efforts, meeting with little success until 1843. Then Congress finally passed the long delayed appropriation, and on May 24th of the year following a telegraph from

Baltimore to Washington was used for the first time. From that time forward the career of the inventor was a series of triumphs, marred only by one serious incident when Morse's claim to his invention was contested, and he was obliged to defend his position in the courts.

A REGRETTABLE CONTROVERSY

In this trial it developed among other things that Doctor Jackson, Morse's fellow passenger on his momentous trip from Europe, maintained that he, and not Morse, was the inventor of the electrical telegraph. He claimed that he had explained to Morse, and had illustrated with sketches, a method of constructing a telegraph which was later usurped by Morse in his experiments. At the trial these claims were not sustained, but were in fact absolutely refuted by the sworn statements of those on board the boat, among these being the captain of the ship, who identified Morse's instrument with drawings which Morse had explained to him in detail on the *Sully*.

Sabine, who may be taken as an impartial judge of this controversy, summarizes the position of Doctor Jackson as follows:

"Doctor Jackson—who possesses an unenviable reputation in America for setting up claims to other people's inventions—in his statements made in 1837 and in 1850, is guilty of considerable self-contradiction, and only in the latter does he even allude to the employment of an electromagnet. Apart from this gentleman's equivocal character and conduct, we do not see anything remarkable in the fact that he should consider himself entitled to some participation in the credit arising from the invention of a telegraph in America. Two men came together. A seed-word, sown, perhaps, by some purposeless remark, took root in fertile soil. The one, profiting by that which he had seen and read of, made suggestions and gave explanations of phenomena and constructions only imperfectly understood by himself, and entirely new to the other. The theme interested both, and became a subject of daily conversation. Then they parted, and the one forgot or was indifferent to the matter, whilst the other, more in earnest, followed it up with diligence, toiling and scheming ways and means to realize what had only been a dream common to both. His labors brought him to the adoption of a method not discussed between them, and Morse became the acknowledged inventor of a great system.

"Fame and fortune smiling upon the inventor, it was natural enough that Jackson, awakening from his unfortunate indolence, should remember his share in their earlier interchange of ideas, that had, perhaps, first directed Morse's attention to the subject of telegraphy. And, although we are compelled to pronounce dishonest those attempts which Jackson made to claim the later and proper invention of Morse—that of the electro-magnetic recorder—and strong as is our confidence in the spotless integrity of our friend, we cannot entirely ignore Jackson—little as he has done—nor deny him an inferior place amongst those men whose names are associated with the history and progress of the electric telegraph in America"[1]

In this connection it is interesting to note that this Doctor Jackson was the same man who contested Doctor Morton's right to the discovery of etherization. As with Robert Hooke, claiming other men's discoveries seems to have been almost a mania with him.

PRINCIPLE OF THE MORSE TELEGRAPH

The principle involved in the Morse telegraph is the same as that which was so graphically illustrated by Professor Henry with his magnet and falling weight referred to a moment ago. As illustrated by this experiment, tapping sounds could be made at any desired intervals by simply making and breaking a current conducted along a wire. If a metal hammer, or armature, is so placed that it is held by a spring at a short distance above a soft-iron core around which is wound insulated wire connected with a galvanic battery, it is obvious that when the current is passing along this wire, making the soft iron a temporary magnet, the metal hammer will be drawn against this core and held there as long as the current is unbroken. On breaking the current, however, the hammer will be released and fly back to its original position. As this magnet can be made to act instantaneously and with great force, a sharp tapping sound will be made by the hammer as it snaps against the magnet when the current is closed.

If a key so arranged that by pressing a button the circuit will be closed and broken when raised is placed somewhere along the course of the wire, the hammer or armature may be made to give a series of taps or blows upon the iron core or magnet corresponding precisely with the pressing and raising of the key-button, since the passage of current is practically instantaneous. If this button arrangement, which is called a "transmitter," is placed at some distance from the magnet and hammer, it is obvious that a person working the button of the transmitter can make certain signals to persons within hearing of the hammer strokes upon the magnet. If certain signals were mutually agreed upon, one tap of the hammer indicating the letter A, two taps the letter B, etc., messages could be sent and received with absolute accuracy.

Such an arrangement is the underlying principle of the Morse telegraph, although when worked out in practical detail and perfected, as was done by Morse, the apparatus is much more complicated. Morse found, for example, that after a certain length of wire had been used the receiving instrument no longer responded to the making and breaking of the current. To overcome this he found it necessary to strengthen and increase the current at certain intervals with "relays," which were referred to a moment ago. This was one of the novel and important factors of his discovery.

Another important feature was a method of recording the messages received other than by sight or hearing. Morse perfected such a recorder, by which the tappings of the receiving hammer were impressed upon a strip of paper so that an operator might interpret the message from the strokes and intervals of the receiver, or might have it as a written impression in dots and dashes on a strip of paper.

The telegraph so perfected represents the practical telegraph of to-day. Hundreds of minor modifications have been made, of course, and are being made year by year, but the principle involved remains the same in all forms of the Morse telegraph, which represents at least ninety-five per cent. of all telegraphs the world over. In England for many years the needle telegraph, used by certain railroads, rivaled the Morse telegraph in popularity, particularly as the famous inventors, Cook and Wheatstone, had given great attention to that form of instrument. But for the last quarter of the century at least, there has been no rival of the Morse instrument that could be considered in any sense a competitor.

MULTIPLE MESSAGES

Early in the history of telegraphy the possibility of sending messages in opposite directions at the same time was conceived, and in 1853 an Austrian, Doctor Gintl, invented an instrument by which this could be accomplished. In this instrument a relay with coils wound with two separate wires was made. In one of these wires the current of the line batteries circulated, and in the other flowed a current from what is called an "equating" battery. These two coils, which were wound in opposite directions on the soft-iron cores, had opposite magnetic effects upon the relays when connected in the proper circuits; so that although the whole circuit of one battery might pass through both relays, only one of them would be affected by messages coming from the instrument designed to affect that particular coil, the messages coming from the opposite direction passing through with no effect. This arrangement, with various modifications, came into general use shortly after its invention.

A somewhat similar device, which acts upon the principle that currents of different intensities are not affected by each other, and only act upon receivers of corresponding intensity, is utilized for sending two or more messages in the same direction, and at the same time, on one wire. Supposing two sending instruments are given different tensions, one high and one low, and two receiving instruments are given corresponding tensions. If messages are sent from the high-tension transmitter, such messages will be received by the high-tension receiver at the end of the wire, no effect being produced upon the low-tension receiver, which will be moved only upon the operation of the low-tension transmitter. If both transmitters are operated at the same time, however, both high- and low-tension receivers will be affected, although independently of each other. In this way it is possible to send two messages at the same time.

This system is utilized also in Elisha Gray's "Harmonic Telegraph" for sending multiple messages. In this, a number of separate magnetic vibrators, which open and close the circuit at the rate of a certain number of vibrations per second, are placed in connection with the wire, with a corresponding vibratory receiver having exactly corresponding vibrational periods to each of the transmitting instruments. Such receivers will only respond to the messages sent by the transmitter of similar vibrational period, so that no matter how many messages are being sent by other transmitters, each vibratory receiver selects its own particular message.

Another "multiplex" arrangement is one in which a circle is divided into as many segments as there are senders and receivers, each segment being connected with a receiver, and a corresponding sender connected with the segment of a similar device at the opposite end of the line. A revolving "contact slider" is so arranged that by revolving rapidly and passing over each of these intervals in succession, each transmitter is allowed to send its message in rotation. This system, first proposed by Lord Kelvin, in 1858, has been developed on practical lines, and wires sending from four to eight separate, simultaneous messages are now in practical operation all over Europe and America.

It was evident, even in the early days of electric telegraphy, that messages could be sent and received by the instruments much more rapidly than the keys could be worked by hand, and automatic transmitters and receivers were soon invented. As early as 1846, Bain invented a method of sending such messages automatically, but an apparatus on similar principles was later devised by Professor Wheatstone, which, with various modifications, still remains in use. In this arrangement the message to be sent is recorded by means of punched holes on a strip of paper. When this strip is passed through the transmitter, these holes cause the automatic transmission of the message, which is recorded at the other end of the line. In this way five or six hundred letters or more can be sent in a minute. This system, with the various modifications of it, is particularly useful where the same messages are to be sent to a number of different places, as the perforated strip of paper can be made in multiples at a single punching.

Many different types of telegraph recorders have been invented since the time of Morse's first instrument, several of these being the experimental inventions of Morse himself. The principles involved in these recorders have been both chemical and mechanical, the mechanical ones, as a rule, predominating. Practical chemical recorders are used, however, utilizing the well-known fact of chemical decomposition by the electric current. For example, if a strip of paper is saturated with some chemical which is easily decomposed by electricity, and in this decomposition changes color, the pressure of an electrical needle upon this strip of paper will produce a mark. If the strip is arranged on rolls which pass it beneath the position of the needle at a uniform rate of speed, dashes and dots may be made by the needle's contact with the paper for a longer or shorter time. This method is found to be entirely practical, and the principle is utilized in many recording devices.

It is quite beyond the scope of this work to go into details of the hundreds of telegraphic devices, for signaling, etc., the numbers of which are being multiplied almost daily, and which have become practical necessities in civilized communities. But it is interesting to remember that such widely divergent mechanisms as the dial-signaling apparatus with which the captain of the ocean liner communicates his commands to the engineer far below in the engine-room, the Atlantic cable with which Europe communicates instantly with America, the button that explodes a submarine mine, and the familiar electric door-bell and call-button, are all developments of Morse's practical application of Michael Faraday's discovery of electromagnetic induction.

II

THE SUBMARINE CABLE

THE story of Robert Bruce and the spider, and the story of Bruces' own perseverance and persistence in the face of adversity, have become classic; but in recent years Bruce's traditional efforts have been equaled, if not eclipsed, by the persistent efforts and unwavering faith of the handful of men who projected and finally perfected the Atlantic cable. Bruce, fighting on the defensive, had conditions forced upon him; but the heroes of the Atlantic cable not only took the initiative but were obliged to keep it in the face of most discouraging public sentiment, financial difficulties, and worst of all, the bare fact that attempt after attempt proved unsuccessful. Contending against defects in the cable structure, broken cables, cables fouled and destroyed by vessels before they could be laid; and finally, after heartbreaking efforts, when a cable was successfully laid across the Atlantic, to have it "burned out" and destroyed by an electrician—all this makes a story rivaling the most vivid imaginings of the novelist. Happily, like the endings of most novels, the last word of this story is a complete triumph for the heroes of the plot; and the names of Cyrus W. Field, Sir Charles Bright, John W. Brett, and Lord Kelvin, must go down in history as having accomplished one of the most difficult feats in history, as well as one of the most useful commercial and economic ones.

The Atlantic cable was not the first submarine telegraphic communication ever projected or accomplished. As early as 1838, a successful cable had been laid across the Hugli River in India, and in 1842, Morse had laid a similar cable in New York Harbor. The great difficulty with these first cables was the fact that effective and permanent methods of insulating had not yet been discovered. Copper wire wound with strings saturated with tar, wax, and pitch, acted well enough for a short time at small distances, but it was not until the discovery that gutta-percha makes an almost ideal insulator, that submarine cables of any length became possible. With this discovery, however, a great impetus was given to cable-laying, and in 1845 a company was formed for laying a cable between England and France, a distance of twenty-five nautical miles.

ENGLAND LINKED WITH THE CONTINENT

The announcement of a company for such a purpose was received in a manner quite beyond the comprehension of the people of the present generation, surfeited as they are with the marvelous accomplishments of applied science, which sends messages through the air, photographs through opaque substances, and performs numerous other seemingly miraculous feats inconceivable to the most imaginative persons of two generations ago. Few people, either in England or France in 1845, believed that the Channel cable could succeed. Those of a suspicious nature denounced the scheme as a gigantic swindle; others derided it as a mad freak of the imagination of enthusiastic visionaries; while one critic naively pointed out that the scheme was impossible on account of the roughness of the Channel bed, believing that the intended method of communication was that of actually pulling upon the cable, like pulling a mechanical house-bell worked by wires.

Nevertheless the projectors completed and laid their cable, and communications were made between England and France. A message of congratulation was sent to Louis Philippe, and public incredulity had just turned into public rejoicing when suddenly the cable ceased to work. It was learned afterward that a Boulogne fisherman, hooking up the cable and being unable to account for such a mysterious-looking "seaweed," had hacked off a section to take home to show his friends.

The cable of 1846 proved conclusively that, for short distances at least, the submarine telegraph was a possibility. But sending a message twenty-five miles through a cable laid in comparatively shallow water is a different matter from sending it two thousand miles submerged in water two miles in depth. Cables insulated with gutta-percha did not conduct the current as readily as did cables of the same size without insulation and suspended in the air, the gutta-percha tending to absorb and retard part of the charge. This difficulty, however, was soon overcome by means of a succession of opposite currents, but the problem that could not be solved except by actual experiment was the effect that might be produced upon the cable itself or upon the electric current by the great pressure of the water at ocean depths.

CYRUS FIELD PROJECTS THE ATLANTIC CABLE

But now a man of business, and not a scientist, became interested in the possibility of cable communication across the Atlantic. This was Cyrus W. Field, an American business man who had made a fortune and retired before he had reached forty years of age. Becoming greatly interested in the attempts at cable-laying in Europe, he crossed the Atlantic and in 1856 succeeded in forming the Atlantic Telegraph Company, capitalized at £350,000. Of this amount Field reserved £75,000 in shares for his own placing in America; but while the English capital was quickly subscribed, little response was given in America, less than one-twelfth of the £75,000 being taken up.

Among the scientific men of this company was the late Lord Kelvin, to whose unwavering faith in the possibility of transatlantic communication, scientific and practical advice, and invention of several marvelous instruments, the ultimate success of cable-laying is in large measure due. For his views were in opposition to many of the leading scientists of the time, many of them much better known than the young Scotch professor.

One instance may be cited as showing how the purely theoretical scientist is perennially bobbing up and "proving conclusively" with theories and dogmas that certain things are impossible, only to have them shown to be perfectly practicable by actual demonstrations. On the announcement of the formation of this company for telegraphing across the Atlantic, Sir G. B. Airy, F.R.S., Astronomer Royal of England, declared that such means of communication was impossible; first, because it was a physical impossibility to submerge a cable safely to so great a depth, and secondly, that no signals could travel for such a distance, anyway. Knowing the type of mind of this kind of scientist, it is probable that long after the Atlantic cable was an accomplished fact, the Astronomer Royal was still maintaining that the thing was impossible, and showing his mathematical calculations to prove it. Fortunately for civilization Sir Charles Bright and Lord Kelvin were scientists of a different type.

With the fund subscribed, the making of a cable was begun at once, and while this was in progress certain ships detailed for the purpose were being prepared to receive the cable, and fitted out with apparatus for laying it. The total space occupied by the cable was too great for any single vessel, there being some 340,500 miles of copper wire alone used in its construction. The English government, therefore, detailed the war-ship *Agamemnon*, and the United States government sent over the *Niagara*. Into the holds of these ships the cable was coiled in great tanks, each coil carefully laid by hand so that it would uncoil readily and without any possibility of even a momentary hitch which might prove disastrous to the undertaking. The *Niagara* was to undertake to lay the European half of the cable, the *Agamemnon* taking up the task in mid-ocean and continuing the work as far as the American shore.

HIGH HOPES—AND FAILURE

By the time the two cable vessels and their fleet of consorts were ready to start, great enthusiasm and faith in the success of the project had been created both in America and Europe, and great personages of the British Empire gathered on shore at the starting point to God-speed the two vessels on their momentous voyage. This starting point was in Valentia Bay, Ireland; and amid tooting whistles and flying bunting the *Niagara* began paying out the cable. But the start was unpropitious, the paying-out machinery not working well, and five miles from shore the cable parted. This was not a serious matter in that depth of water, however, and the ends of the cable were soon spliced, the paying-out machinery adjusted, and the *Niagara* once more resumed her voyage.

The heartbreaking suspense of the promoters on board the fleet of cable-boats may be readily imagined. Hour after hour, and mile after mile, the threadlike line of wire must keep dropping continuously from the stern of the ship, must be regulated so that it did not run out too fast and yet not restrained with sufficient force to break it. Not once must the boat, or the machinery for paying out, stop after deep water was reached, as the weight of the cable would cause it to break if checked even momentarily.

As the *Niagara* continued successfully to pay out the cable hour by hour, however, the promoters breathed more easily, and the messages and communications which were being constantly sent from ship to shore in order to test the cable, were supplemented by cheerful messages from the officers to friends on land, and to friends in America, by way of outgoing vessels from England.

The unknown effects of the deep-sea pressure were tested and found not to interfere with the working of the cable on the third day of the voyage when the deep ocean was reached, and the cable continued to work uninterruptedly. With this bugaboo safely behind them the spirits of all concerned reacted and mounted to the highest pitch of anticipation. The third day passed and all was going well. The fourth bade fair to be a repetition of the third, when suddenly, without a moment's warning, the cable parted and sank.

The cause of the accident was the failure to release the brakes of the paying-out machine at a critical moment—a turn of a hand-wheel in the wrong direction by an over-anxious workman—with the result that a fortune in money was lost and the hopes of two continents shattered. The manipulation of this vital part of the cable machinery had been undertaken by Charles Bright in person, who had stood by the machine most of the time, day and night, since the beginning of the trip. But having occasion to step forward to see how the cable was coming out of the hold, he left the paying-out machine for a moment in charge of a mechanic, a man perfectly familiar with the construction and running of it. Bright had hardly left his place, however, when he heard the machinery stop. Rushing back he called to the mechanic to release the brakes; but in the crucial moment of excitement the man turned the release wheel the wrong way, and the cable snapped at once.

The high character of Bright is shown in the matter of his official report of this unfortunate accident to the company. One can imagine what his feelings must have been toward the man whose mistake meant so much to him, for Bright's heart and soul were in the enterprise. But in this report, far from naming the man or blaming him, he simply says, "On examining the machine I found that the brakes had *not* been released, and to this, or to the hand-wheel of the brake being turned the wrong way, may be attributed the stoppage and consequent fracture of the cable." It is gratifying to know that the man who could thus restrain his feelings was destined finally to succeed in this and many other great undertakings.

It was a sad spectacle presented by the "Wire Squadron" a few days later as it crept back into harbor, defeated, and disgraced in the eyes of the critics. No enthusiastic well-wishers gathered there to encourage it. Gloom was everywhere—except in the hearts of the "I told you so" croaking critics. Gloom and depression—but not dejection, at least in the camp of the promoters and stockholders; for money was subscribed, and seven hundred miles more cable ordered made at once.

A SECOND FIASCO

The experiences of the first attempt were profited by, and, among other important innovations, a self-releasing brake was devised by Bright and a Mr. Amos which overcame the possibility of a repetition of the accidental breaking of the cable by the paying-out machinery. Another great invention, made by the moving scientific spirit of the enterprise, Professor Thomson (afterward Lord Kelvin), was that of his mirror-speaking instrument, or "marine galvanometer," which eventually revolutionized long-distance electric signaling and testing on shipboard. This instrument consisted of a tiny magnet and a reflector, weighing together about a grain, with which transmitted messages were magnified by reflected light, so that the faintest current could be detected and signals interpreted.

Early in 1858, the new cable being completed, a second attempt was made. This time, however, a new plan was adopted, and instead of beginning the cable-laying from one end, both ships, the same *Agamemnon* and *Niagara* as before, proceeded to a point in mid-ocean, spliced the two ends of the cable together, and headed in opposite directions paying out the cable as they went. When three miles apart the cable broke by becoming entangled in the machinery of the *Niagara*. Both ships at once put about, a new splice was made, and again they headed for opposite shores. All went well for a few hours when the cable again parted—this time apparently somewhere at the bottom of the ocean. Again both boats put about, returned to the rendezvous, and spliced the cable for a third time.

This time things looked more hopeful, and mile after mile of cable was laid, everything moving smoothly. Something over a hundred miles had been reeled off by each ship—a total of two hundred and twenty-three miles of the wire strand—when suddenly, without any warning, the cable again parted. As signals could not be exchanged between the ships, there was nothing for it but to relinquish the undertaking and return to Queenstown as agreed upon before starting.

SUCCESS AT LAST

The meeting of the board of directors of the Cable Company was a gloomy affair. The chairman probably voiced the feelings of a large share of the members when he suggested that the cable remaining on shipboard be sold as junk to the highest bidder, or words to that effect. But Cyrus Field was there, and Bright, and Brett, and with them the indomitable Professor Thomson and Curtis Lampson. And once more the indomitable "Wire Squadron" was ordered to sea.

There was no pomp and display in this departure. The ships crept out of the harbor more like sea-wolves departing after an unsuccessful raid—a handful of ships carrying a party of cracked-brained visionaries, to whom two tolerant governments had generously loaned their vessels. This was on Saturday, July 17, 1858, and it is probable that few persons, either in Great Britain or in America, aside from immediate friends and relatives of the members of the expedition, gave a single thought to the movements of the boats or knew or cared what they might be doing.

But on August 5th, the world was awakened from its lethargy with a start. A message had been flashed from Valentia to the Board in London. "The *Agamemnon* has arrived at Valentia," it read, "and we are about to land the end of the cable. The *Niagara* is in Trinity Bay, Newfoundland. There are good signals between the ships." It was from Charles Bright (made Sir Charles a few days later), announcing that the Eastern and Western hemispheres were no longer separated by weeks, but only by seconds.

England received the news with the unbounded enthusiasm that can only come with complete surprise, or after intense expectancy. "The rejoicings in America," says *The Times*, "both in public and private, knew no bounds. The astonishing news of the success of this unparalleled enterprise, after such combats with storm and sea, created universal enthusiasm, exaltation, and joy, such as news perhaps never before produced by any event, not even the discovery of the Western hemisphere."[1]

Congratulatory and commercial messages were soon being sent and received, and people of both hemispheres were becoming accustomed to receiving news every morning which two months before must have been two weeks old at least, when on October 20th, after a total of 732 messages had been sent across the ocean, the cable ceased to work. The knowledge of the electrician had not kept pace with the engineer, and the destruction of the cable had resulted from too strong and misapplied currents.

IMPROVED METHODS AND NEW CABLES

The depression following this catastrophe, however, was not to be compared with that following some of the earlier ones. A successful cable had been laid and operated, and even the most short-sighted could see that the scheme was no longer impossible or visionary. But would a cable ever pay? That was the vital question. Cyrus Field thought it would, and his associates agreed with him. Meanwhile shorter cables were being laid in the Mediterranean Sea, the Red Sea, and other places, and both engineer and electrician were perfecting their knowledge of cables and cable instruments. The Civil War in America for a time diverted the efforts of the cable company from attempting another transatlantic cable. By the time of the close of the war, however, in 1865, methods of cable-making, cable-laying, and cable instruments had been so greatly improved that the promoters of the original company had come to have very great confidence in their project, and this feeling was shared by many promoters, as shown by the fact that other companies had been formed for the same purpose.

In 1865, therefore, the attempt to lay a cable across the Atlantic was renewed. This cable differed considerably in construction from the original one. It was one and one-tenth inches in diameter and weighed thirty-six hundred pounds per mile in the air, but only fourteen hundred pounds in water. There had been so many obvious disadvantages in the method of laying the cable in sections by two ships that it was decided, if possible, to have a single ship, carrying all the cable, lay it directly from shore to shore—if a ship large enough to carry the enormous weight of the new cable could be found.

The ideal ship for this purpose was at that moment lying idle at her dock because she had not proved a commercial success. This was the *Great Eastern*, the monster vessel of 22,500 tons displacement, which had been completed in 1858, half a century in advance of her time. She was propelled both by paddle-wheels and propeller, and her enormous size and corresponding steadiness made her an ideal boat for cable-laying. The new cable was therefore stored aboard and the laying commenced. On this voyage the tireless promoter Field and the scientist Sir William Thomson were aboard with many others either directly or indirectly connected with the enterprise.

The advance that had been made in cable-laying since the achievement of 1858 was shown in many ways on this voyage. For example, if a fault was discovered in the cable after it had been dropped overboard, it was now possible to reverse the machinery, pick up the cable to the point at which the fault occurred and repair it. This was necessary on one occasion when the fault had been passed ten miles before discovery, but this was accomplished successfully and with no very great difficulty. After laying 1186 miles of cable, however, and when the end of the voyage was almost in sight, the cable parted and could not be recovered. Picking-up machinery had been carried by the boat for just such an emergency, but this machinery was not effective, although the cable was grappled and raised part way to the surface several times. The attempt to complete the laying was therefore abandoned for the moment.

By the middle of the following year, however, new and better picking-up machinery had been devised, and on June 30, 1866, the *Great Eastern* again started laying another cable. Fourteen days later her work was completed successfully, and communication between the continents began at once. Not satisfied with this success, the great ship returned to the scene of her mishap of the preceding summer, and after overcoming many difficulties succeeded in grappling the broken end of the cable of '65, spliced it to a new cable, and completed the second workable cable within a few weeks after the completion of the first.

This was about the first and last useful work of any kind ever accomplished by the *Great Eastern.* It was perhaps enough for any one vessel to have accomplished the "greatest undertaking of the century." But this undertaking was the only useful purpose to which the boat could be put, and a few years later she was broken up.

Since the completion of the 1866 cable great advances have been made in all phases of submarine telegraphy. At present the total number of miles of such cables is considerably over two hundred thousand, their cost being from one thousand to fifteen hundred dollars per nautical mile. The most expensive single item of expense in these cables is the cost of the gutta-percha used, but as nothing less expensive has been found to replace it, this great cost is unavoidable.

Obviously with these two hundred thousand and more miles of cable, repairs are constantly necessary. But repairing submarine cables to-day is not the onerous task that it was in the early days of cable-laying. When a fault or fracture occurs at the present time, it is possible to determine approximately the position of the fracture by electrical tests from the shore. The repair ship is then sent to the point indicated and the cable raised and repaired. In order to raise the strand the ship drags the bottom transversely with a five-or six-pronged anchor, or grapple, a dynamometer indicating when the cable has been caught.

In very deep water, unless the cable has been hooked near the broken end, the raising of it directly to the surface would cause so great a strain that another fracture would probably result. To obviate this it is raised a certain distance, perhaps half-way to the surface, and then held in position by a buoy attached to the grapple rope. At some little distance from this point the cable is again hooked with another grapple iron, and unless the depth be extreme, may now be brought directly to the surface, as sufficient weight is relieved by the buoy and grapple to allow this to be safely done. In this way repairs may be made with comparative ease and rapidity.

The life of a submarine cable under ordinary circumstances has not as yet been definitely determined—which is the same as saying that it is a long one, since numerous cables have been working continuously for many years, and there is every reason to believe that they will continue doing so for many more to come. They must be constantly attended to and repaired, however, and the cost of these repairs sometimes amounts to fabulous sums. The cable of the Direct United States Cable Company, laid in 1874, has cost, on an average, $40,000 per annum for the last thirty years.

INSTRUMENTAL AIDS

The instruments used for sending and receiving messages over two thousand miles of cable are not the comparatively simple transmitters and receivers of land telegraphy, where relays can be installed and the current increased at various points along the line. The instrument first used for receiving cable messages was Lord Kelvin's "marine galvanometer" referred to a moment ago. When this little instrument is suspended near a fine-wire coil, it takes a position at right angles to the plane of the coil when the current is on, being deflected to right or left according to the direction of the current. These movements to right or left are interpreted as dots and dashes respectively, and thus the Morse code can be used as in land telegraphy.

Another instrument that came into use shortly was the "spark recorder"—an instrument so arranged that sparks were projected against a surface of paper, or some other sensitized surface, passing at uniform speed. The message was thus recorded as an undulating line of dots or perforations which could be read and transcribed into writing by the operator.

But this instrument was soon replaced by another instrument, the "siphon recorder," first patented by Lord Kelvin in 1867. In this, a tube of ink is so arranged that as the message comes over the wire fine drops of ink are projected upon a piece of paper in a wavy line, the dots and dashes of the Morse code being represented by deflections of the line of ink-dots to one side or the other of a central line on the paper.

Since this early invention of the siphon recorder many improvements have been made in the instrument, several of them by Lord Kelvin himself. The principle remains practically the same, however, and siphon recorders of various kinds are now used almost exclusively in submarine telegraphy.

III

WIRELESS TELEGRAPHY

ON Thursday, December 12, 1901, at 12.30 P.M. Guglielmo Marconi at a station in St. Johns, Newfoundland, received a communication of the letter S—three dots of the Morse code—sent through the air from the wireless telegraphy station at Poldhu in England. This was the first wireless communication ever sent across the Atlantic Ocean. The news of this event created enthusiasm all over the world, and excitement in certain commercial centers, but it can hardly be said to have created any astonishment: the present generation has become too accustomed to marvelous manifestations of electricity.

The success of Marconi and several other prominent scientists in the development of wireless telegraphy is the outcome of a long series of experiments dating back almost to the beginning of the nineteenth century. Most of these early experiments, however, were attempts at sending wireless messages through the earth or through water rather than through the air, the fact that dry air is a poor conductor of electricity for many years preventing experiments in telegraphing through this medium without some mechanical means of conduction. In the middle of the eighteenth century Watson discovered that water could be made to take the place of wires as the return circuit of two batteries. The fact that the earth could be made to perform the same function, however, was not discovered until many years later.

In experimenting with land electricity in 1837, Steinheil, in England, made the accidental discovery that the earth could be made to take the place of the return wire of his telegraph. It had occurred to Steinheil that the two rails of the railroad track could be utilized for sending telegraphic messages in place of two wires. He therefore connected the wires from the telegraphic instrument with the rails of the track, arranging a similar instrument at the station a few miles distant. He found, however, that messages could not be transmitted in this manner, and in investigating to determine the cause of this failure, he discovered that the current, instead of passing along one rail and returning by the other, made a short cut through the earth from rail to rail. This suggested the possibility of utilizing the earth itself as a conducting medium for wireless telegraphy, although experiments in this direction were without results for many years.

WATER AND EARTH AS CONDUCTORS

About five years later, in 1842, Samuel Morse succeeded in sending wireless messages, first across a canal and then across a river something like a mile in width. He did this by immersing the ends of two telegraph wires running parallel along the opposite banks for some distance, the four ends of these wires being immersed at points in the river at which the wires would have crossed the stream had the circuit been continuous. If one imagines two iron bridges crossing a narrow stream at some distance apart, the ends of these bridges being connected by two wires running parallel on opposite banks, it is obvious that if telegraph instruments are inserted anywhere along these wires, messages may be sent and received, a complete circuit being formed by the bridges and the wires connecting them. If the bridges were removed, however, and the ends of the wires at the place of removal immersed in the stream by means of metal plates at the points corresponding to the position of the ends of the bridges, it is found that messages may be sent as readily as before the bridges were removed, the water or the bed of the stream completing the circuit. This is the principle upon which Morse constructed his wireless telegraph. But the maximum distance at which he was able to convey messages was something like a mile; and in order to do this he found that it was necessary to have his wires extended along the banks at least three miles. In other words the relative distances at which messages could be sent through water was as one to three in comparison with the length of the wires on shore.

No particular advance was made in wireless telegraphy from this time until about 1880, after the invention of the telephone. About this time, however, Prof. J. Trowbridge, of Harvard, found that if a dynamo or coil had two terminals in the earth, an interrupted or alternating current passing between them may be detected by means of a telephone receiver, which is extremely sensitive to feeble interrupted currents. Messages in the form of verbal communication could not be transmitted in this manner, but if a telegraph instrument was used the clicking could be readily detected, and messages by the Morse code read at a considerable distance. Trowbridge suggested that by this means it might be possible to establish transatlantic communications. He suggested the use of this method, or a modification of it, for the communication between vessels at sea, and his suggestions were tested practically by Graham Bell, of telephone fame. In his experiments Bell was able to send and receive messages from ships half a mile apart; but at long distances his attempts were unsuccessful. Messages thus limited were of course of no practical importance, and experiments in this direction were soon abandoned.

In 1882, Sir William H. Preece turned to practical account the foregoing experiments of Morse and Trowbridge, by sending messages across the Solent to the Isle of Wight from the mainland of England. The cable between these two places having been damaged and rendered useless, Preece erected parallel wires on the opposite shores arranged in a manner similar to the wires of Morse, but having a telephone receiver inserted, which made the detection of feeble currents possible. This wireless telegraph worked satisfactorily and was used for some time until the cable was repaired. This was one of the first successful attempts to turn wireless electric telegraphy to practical account.

Three years later, in 1885, Thomas A. Edison patented a system of wireless telegraphy whereby moving trains could send and receive messages at any point along the line while going at full speed. This system was installed on the Lehigh Valley Railroad in 1887. Although the practical working of this telegraph was entirely satisfactory, it was not found to pay commercially, as there was not sufficient demand for such a system, and it was shortly abandoned.

In 1892, Sir William Preece and Mr. A. W. Heaviside, experimenting with parallel telegraph lines situated some ten miles apart, found that they could send and receive messages readily at that distance. Their system was given a practical test shortly after, communication by this means being attempted between the coast of Wales at Cardiff and two small islands situated about three and five miles respectively from the shore. On Flat Holm, the nearer of the two islands, messages were sent and received successfully from the mainland; but on Steep Holm, two miles farther out, the signals could be detected, but not distinguished with sufficient clearness to be read.

A little later than this Mr. Willoughby S. Smith and Mr. W. P. Granville installed a system of communication with Fastnet Rock, some seven miles off the coast of Ireland, which, although not remarkable for the distance to which the messages were sent, was very important commercially. Cable communication with this rock, on which is located an important lighthouse, was constantly interfered with by the breaking and wearing out of the cable, due to the violence of the waves in that vicinity as well as the nature of the ocean bed. To overcome this, Smith and Granville cut the cable at some distance from shore and grounded the end of it with a mushroom anchor at sufficient depth to be beyond the destructive action of the waves. Wires were then passed over the rock and submerged on both sides and a telegraph plant installed, utilizing a modification of the system employed by Sir William Preece in his experiment. This arrangement solved the question of constant communication between the lighthouse and the mainland.

EXPERIMENTS WITH "HERTZIAN WAVES"

In 1886–7, the great discovery of Dr. Heinrich Hertz that there are waves in the ether apparently identical with the light waves but of much lower pitch or period, called the attention of the scientific world to the possibility of using these vibrations for wireless telegraphy. The existence of such "Hertzian waves," electromagnetic in nature, had been suggested several years before by Clerk-Maxwell, but his theory had not been practically demonstrated until the classic experiments of Doctor Hertz. It was found that these waves were comparatively tractable and that they could be dealt with as if they were light waves—could be reflected, refracted, and polarized. The possibility of utilizing such waves in wireless telegraphy was appreciated at once, their action being the basis of all modern wireless telegraphs.

The obstacle which opposed the use of such electromagnetic waves at a great distance was the difficulty of detaching them, rather than that of sending them. But in 1890–1 a "coherer" was invented by Doctor Branly in Paris which was extremely sensitive to these Hertzian waves and by means of which the presence of such waves might be detected. Doctor Branly, therefore, is usually credited with having developed the little instrument that made possible the modern wireless telegraph. But it seems that as early as 1880 the discovery of such a coherer had been made by Prof. D. E. Hughes, although this discovery had attracted comparatively little attention. When the discovery of Doctor Branly's became known, Sir William Crookes at once recalled that he had seen a somewhat similar device made ten years before by Professor Hughes. Investigation of this showed that Professor Hughes had anticipated Doctor Branly's discovery by several years, although Dr. Branly's coherer, rather than that of Professor Hughes', must be credited with playing the important part in the development of wireless telegraphy.

The principle of this coherer depended upon the action of brass filings confined within a vacuum tube, these filings being so sensitive to the Hertzian waves that the latter may be detected at great distances. Making practical application of this discovery, Sir Oliver Lodge, in 1893, experimented with a pair of knobs, each connected with a Leyden jar placed in the same circuit, and a battery and a bell. By this instrument, strokes of the bell could be produced by "syntonic" response of the electric vibration created by a signal jar some distance away. In order to produce this effect the jars and their circuit had to be accurately "tuned"—that is, have a corresponding number of electric vibrations per second.

This instrument of Sir Oliver Lodge's is probably justly considered the ancestor of all the more recent types of wireless telegraphs, in which the vibrations, or syntonic responses, are similarly dependent upon accurate tuning. It was by some such apparatus, or modification of it, that Prof. A. Popoff, of the Cronstadt Torpedo School in Russia, was able, in 1895, to send messages successfully to a distance of five kilometers.

Naturally the scientific world was thrown into a state of intense expectation at the possibilities of these telegraphs, and various investigators all over the world succeeded in producing more or less successful wireless telegraphs. Just what position a later generation will assign these pioneers in the history of wireless telegraphy cannot, of course, be now determined. One fact, however, cannot be gainsaid: the man who first succeeded in transmitting messages across the ocean was Guglielmo Marconi.

THE WORK OF MARCONI

Marconi did not discover any new and revolutionary principle in his wireless-telegraph system, but rather he assembled and improved a vast array of more or less scattered facts, unified and adapted them to the required end. Morse did the same thing with the land telegraph; yet no one will belittle the part he played in introducing the practical telegraph. Possibly future generations will regard Marconi as the Morse of wireless telegraphy.

Between 1894 and 1896 Marconi perfected a most important part of his telegraph, the coherer for detecting electric waves. This little instrument is a glass tube less than two inches long and of less diameter than the ordinary lead-pencil, having two silver plugs sealed into it, each plug with a platinum wire extending from the end of the tube. The silver plugs fit tightly into the tube, completely filling it except for a little space between their ends in the middle of the tube, this space being about one millimeter in length. The little chamber so formed is filled about half full of nickel and silver filings. The air in this space is exhausted and the tube permanently sealed.

Under ordinary circumstances the grains of the nickel and silver powder in the little chamber between the ends of the plugs lie about "higgledy-piggledy," just as any ordinary filings would do under similar circumstances. But when the electric waves fall upon them they are polarized and assume definite positions, in much the same manner as do iron filings on a piece of paper when a magnet is passed beneath the sheet. Once the filings in Marconi's coherer have been so arranged by the action of the electric waves they tend to remain so, and would thus furnish no further means of detecting succeeding waves unless they are disarranged in some manner; but if the tube is tapped, the grains fall into their original position of disarrangement, instantly "lining up" as soon as the waves again fall upon them.

For practical application in wireless telegraphy a mechanical device is used which, by a series of extremely rapid and gentle tappings, oscillates the little tube in a manner barely perceptible to ordinary sight. This oscillating tube is connected with a Morse printer, and so arranged that a short train of oscillations registers a *dot*, while longer periods of oscillations register *dashes*. If, then, the electric waves are made to fall upon the coherer (or receiver, as it may be termed) in longer and shorter intervals from the transmitting instrument, a series of dots and dashes may be made at will—in short, the letters of the Morse code produced.

Another great improvement in Marconi's wireless system was the introduction of his vertical "air-wire" or "aerial," which is a vertical wire carried to a great height on poles or by means of a kite, such a wire acting as an electric-wave absorber, collecting the waves to act upon the little coherer. A great many of these are sometimes used in combination, such "wave-gates" being established at various Marconi stations for long-distance messages. These aerials are also installed on the masts of ships; in such an arrangement one knob of the exciter is attached to a heavy insulated wire which is then led up the mast, terminating at the top in a cylinder or sheet of zinc, or a piece of wire netting.

METHODS AND RESULTS

All these things sound very intricate and complicated indeed, and it might be supposed that the actual sending and receiving of wireless messages by this system is a difficult matter. As a matter of fact the operating is simplicity itself to the telegraphist. His actions are practically the same as if he were sending an ordinary land-telegraph message. When he works the key of his sending instrument, his dots and dashes set up currents in a large secondary coil which pass as sparks across certain "spark-gaps" up along the air-wire of the pole to the terminal at the top, whence they are scattered broadcast. Some of these are gathered in by the wires on the poles at the receiving station, are carried down to the detector that sets in motion the Morse instrument, which sounds or prints the message just as in the case of the ordinary land telegraph.

From this it is obvious that the messages thus sent are not really transmitted in any aimed direction, but are scattered in all directions, and that they would be received and recorded at other receiving stations than the one intended. To prevent this a system of "tuning" has been introduced, so that only instruments tuned to a certain number of vibrations per second affect each other. Unless the number of vibrations is nearly the same, instruments tuned in this manner will not be affected by messages from other instruments, and will select out only messages intended for themselves and sent out by similarly tuned transmitters. If some such arrangement as this were not possible, wireless messages would be so hopelessly jumbled as to be unintelligible; and indeed in practice serious difficulties are sometimes encountered where a number of systems are working within "striking" distance of each other.

The progress of wireless telegraphy during the past ten years has been so rapid as to seem like a succession of triumphs. From the sending of wireless messages a few hundred feet by Marconi in London, in 1896, until the transmission of complete messages across the ocean in 1902, seems but a series of rapid steps, certainly unequaled in any previous field of telegraphic progress.

Marconi's first attempts at wireless telegraphy were made in his native city of Bologna as early as 1895. The following year he went to London and applied for patents. Here he submitted his plans to the postal-telegraph authorities, having at their head Sir William Preece, himself a prominent investigator in wireless telegraphy. In order to test the wireless apparatus a sending and a receiving station were located on the roof of the post-office building and in a small room a hundred yards away; and the experiments here conducted were followed by other trials at longer distances.

Early in 1897, Marconi, continuing his experiments in England, made attempts at sending messages a considerable distance over bodies of water. While working at one of these he made the discovery that a long air-wire was most essential to successful communication, even at comparatively short distances. In this experiment he was attempting to send wireless messages to an island a little over three miles from the mainland. One of the poles for supporting air-wires was ninety yards high, but the other one, situated on the cliff of the water's edge, was only about thirty yards in height. For two days unsuccessful attempts were made with this arrangement, and they were watched by several scientists who were studying the subject on the spot and assisting Marconi in his efforts. The attempts were about to be abandoned, for the moment at least, as the cause of failure could not be determined, when it occurred to the inventor to lengthen the air-wire by splicing it down to the water's edge, a distance of twenty yards more. The result was the immediate response of the receiving instrument to the messages sent from the other station, every letter being correctly recorded.

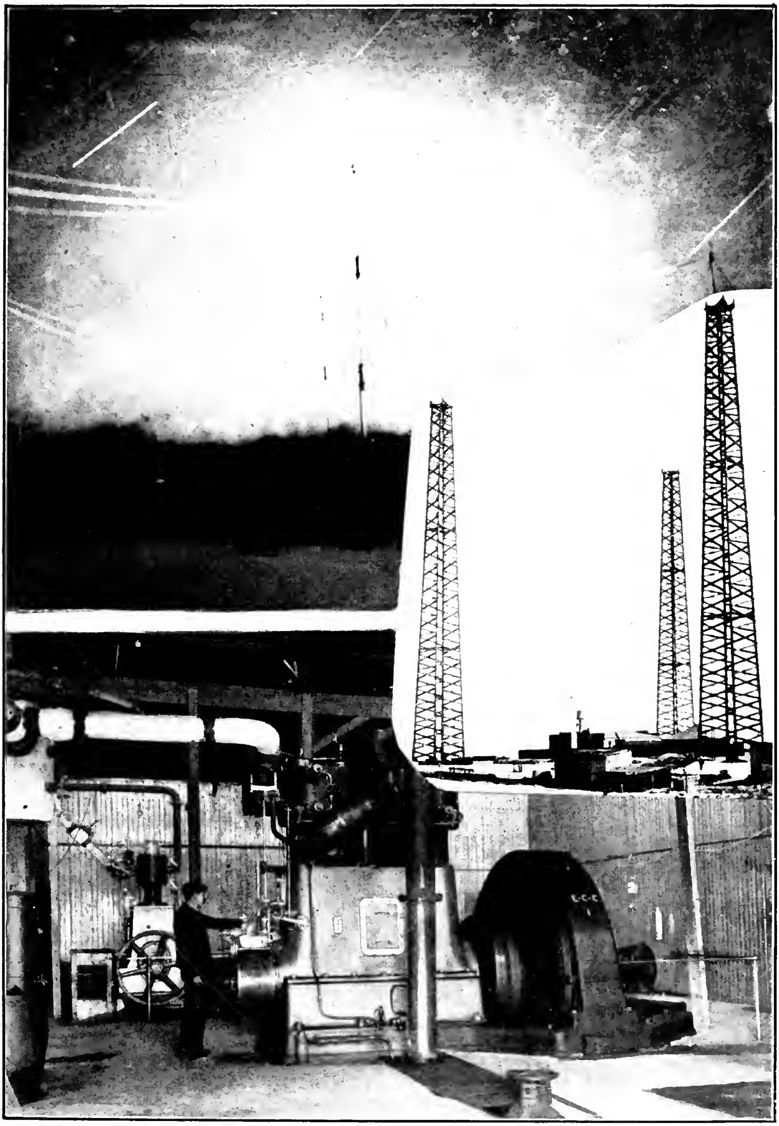
Longer distances were tried at once, and within a few months it was possible to send messages across the English Channel. Stations were established at points in England and France, and communications of all kinds passed continually between these points for several months. During this time it was ascertained that such atmospheric conditions as fog, for example, did not interfere in any way with the transmission of messages, but on the contrary facilitated them. Electrical conditions of the atmosphere, however, affected the wireless system in much the same manner as they affect the ordinary telegraph.

About this same time an epoch in telegraphy and navigation was made by the installation of wireless instruments on board one of the Channel boats in the North Sea. It was found that the masts of the boat afforded excellent means of establishing the air-wire, and that communication could be kept up continually between the boat and the shore station during the voyage. If anyone had ever doubted the utility of such a system, which is hardly likely, these doubts were soon dispelled by an incident which occurred soon after the establishment of the wireless system on this boat. In one of her passages she sighted a small vessel which had run ashore in a dangerous position, imperiling the lives of the crew. The position of the vessel was such that it was impossible to give assistance from the Channel boat with safety. Messages were therefore sent at once by wireless to the land station, giving the position of the stranded boat and asking that assistance be sent at once from one of the life-saving stations on the coast. The crew was successfully rescued a few hours later.

The wireless system was soon found to be most satisfactory in solving the vexatious question of communicating with lightships anchored at some distance from land. Cable communications with such vessels is out of the question because the action of the waves and the constant moving about of the vessel wears out a cable in a short time. With the wireless system, however, these vessels are now kept constantly in communication with shore—a most important thing in case of accident to the lights, or to the vessels themselves.

TRANSATLANTIC MESSAGES

By the autumn of 1901 Marconi had perfected his telegraph so that he determined to attempt to send messages across the ocean. He therefore sailed to his American receiving station in Newfoundland to make the attempt. By prearrangement, the station in Poldhu was to send messages at stated intervals, and at a certain time during each day after Marconi's arrival. The message agreed upon was to be three dots, indicating the letter S of the Morse code. This was to be repeated a certain number of times at intervals of three minutes between the hours of three o'clock and six o'clock P.M., English time, which would be from about 11.30 A.M., to 2.30 P.M., Newfoundland time. On Dec. 12th,



MECHANISMS INVOLVED IN WIRELESS TELEGRAPHY.

The lower figure shows a dynamo used in generating a current for transatlantic messages. The middle figure shows the approved method of construction of towers to carry the wires at a receiving station. The upper figure reproduces a photograph taken at night at a wireless station. The electrical display so vividly recorded on the photographic plate was altogether invisible to the eye.

about noon, these messages were received repeatedly and unmistakably at the St. Johns' station, and they were again heard at intervals on the following day. The miraculous had been accomplished; a message had crossed the Atlantic and been recorded without the aid of any mechanical conductor except that furnished by nature.

In the meanwhile, however, other inventors besides Marconi, in almost every other country, had been experimenting, and naval and merchant vessels were being equipped with wireless apparatus. Wireless messages to and from vessels two days after leaving their docks, to and from friends on shore, became a fad on transatlantic liners; and passing vessels fifty or one hundred miles apart communicated important news to each other or "talked" together for hours as they passed. As the sailing points of most vessels are not from the extreme points of land, and as wireless stations are located in such positions, it was possible to send communications from ship to shore several days after the boat had sailed. A steamship sailing from Antwerp, for example, which passed around the southern coast of England without touching, might be able to keep up her communication with shore fully three days after sailing; and Marconi soon improved his instruments so that at a much longer distance messages might be received on shipboard, even when the vessel was unable to send back replies.

TUNING THE MESSAGES

In March of 1902, Marconi, on the steamship *Philadelphia*, was able to receive messages at a distance of almost 1550 miles from the sending point, these messages being actually in words and not mere predetermined signals. Mere signaling could be determined at a distance something over two thousand miles. On this eventful voyage the fact was established by Marconi that such messages could only be received by a vessel, or vessels, tuned to the same electrical pitch as the shore instrument, and that no insurmountable interference would be offered by messages of a different pitch passing through the atmosphere at the same time. This was established by the fact that several other vessels equipped with Marconi instruments, but keyed to a different electrical pitch, had been on the ocean at the same time, and had been sending messages continually during the passage. The *Umbria*, for example, had been nearer the sending station, and in the same receiving zone as the *Philadelphia*, and yet she had neither received these messages nor had her own messages been interfered with by them.

This seemed to establish Marconi's contention, which had heretofore been greatly doubted, that different sets of instruments might be worked within short distances of each other—within distances of five inches, the inventor said—without interfering with each other; and his messages were assured against possible "tapping of the circuit," by the two hundred and fifty different "tunings" that he was able to give his instrument. "It seems to be a matter of popular belief," wrote Marconi, "that any receiver within effective range of the transmitter is capable of tapping each message sent, or in other words, that there can be no secrecy of communication by my system. Were this so, a very important limitation would be imposed upon the practical usefulness of the system; but by the introduction of improvements and radical modifications in the system, and by a systematical application of the principles of electrical resonance, this objection has, in a very great measure, been overcome."

THE PRACTICAL STATUS OF WIRELESS TELEGRAPHY

On December 21, 1902, three entire messages, of considerable length, were sent between Poldhu and the Table Head station on Cape Breton Island, these being the first complete messages ever sent across the Atlantic. Four weeks later congratulatory messages between King Edward VII and President Roosevelt were exchanged, establishing officially the possibility of practical wireless telegraphy at long distances.

Some of the conclusions reached by Marconi in his extensive experiments are both interesting and instructive. He finds that wireless telegraphy is much more effective over marine areas than over ordinary land surfaces, the relative distance to which such messages may be sent being in the proportion of about two to one. He finds, furthermore, that atmospheric conditions, such as ordinary rain- or snow-storms, high winds, etc., do not seriously affect the wireless signals, although, of course, electrical storms are disastrous to them. Air-wires fixed upon poles about two hundred feet in height give the most uniformly satisfactory results; but strangely enough there is no advantage in placing the pole on a high hill for marine signaling. He has found also that certain geological formations are more responsive than others, although this phenomenon cannot be explained, as the action of the earth in connection with a wireless system is not as yet understood.

The present state of wireless telegraphy may be summed up in the statement that it is entirely practical commercially, even between points separated by an ocean. Continents, lightships, war vessels on long cruises, and islands situated in tempestuous waters, have all been brought into continuous communication with shore points, and at a much less expenditure of money than is possible with submarine cables.

The history of the wireless telegraphy up to the present day is comparable with the history of submarine cables between 1858 and 1866. The cable of '58 carried a few messages and then ceased to work. Other shorter cables were laid, studied and improved upon, and by 1866 the first really successful transatlantic cable was laid and operated. Similarly in 1902 wireless messages were sent across the Atlantic—messages of sufficient length to prove the possibility of accomplishing such a thing—and finally regular communication on a paying commercial basis for transatlantic messages has been established. No one now seriously doubts that the millions of dollars' worth of submarine cables now at the bottom of the ocean is doomed to go the way of the stage-coach and pony express. They have served their purpose and, fortunately, have "paid their way" well; but that they are obsolescent few thinking people will pretend to doubt.

At the present time at least a dozen systems of wireless telegraphy are in use, in various parts of the world. These all resemble one another closely, although each has some features specifically different from any other. Thus the DeForest system, the invention of the American, Lee DeForest, which made such a good record in the Far East during the Russo-Japanese war in the service of the London *Times*, employs alternating-current generators as a prime source of electric oscillations. In this the filings-coherer is not used, but in place of it a "responder" which utilizes a telephone at the receiving end.

Among the other well-known systems in general use are the Lodge-Muirhead system, employed in Great Britain; the Slaby-Arco system, the Braun-Siemens-Halske system, in Germany; the Branley-Popp system, used extensively in France, the Rochefort system, used in the French navy, the Ducretet-Popoff system of Russia, the Fessenden system, and numerous systems operated by ambitious amateurs, which sometimes interfere with the workings of the regular commercial lines.

Four different wireless systems are in use by various departments of the United States government. The navy uses the Slaby-Arco system; the army, the Braun system; the Army Signal Corps, the Wildman system; and the Weather Bureau, the Fessenden system.

IV

THE DEVELOPMENT OF THE TELEPHONE

FULLY to understand the action of the telephone it should be recalled that all sounds are produced by vibrations of matter, and that any sound to be appreciated by the sense of hearing must be conveyed to the sense organs of the ear by the repetition of sound vibrations through some such medium as air, water, iron, etc., air of course being the usual medium. Any body from which sound proceeds, therefore, is in a state of vibration. This may be demonstrated by the simple experiment of striking a thin glass jar, causing it to vibrate and produce sound, the vibratory motion being distinctly felt if the jar is touched lightly when the sound is loudest, and gradually ceasing as the sound diminishes. The same vibrations and sounds may be produced by drawing a violin bow across the top of the jar; and if little balls of wood are suspended by several inches of string so that they just touch the sides of the jar near the top, these will be thrown into a state of vibration, oscillating back and forth against the jar as the violin bow is drawn across it. In this way the sound vibrations are made evident to sight as well as hearing.

In this experiment the air acts as the vibrating medium for conveying the sound waves from the glass jar to the ear; for if the jar were not surrounded by some medium capable of transmitting similar vibrations, no sound could be heard. If, for example, the jar were in a vacuum, the sound of its vibration would not be conveyed to the ear. This was demonstrated by the striking experiment made by Francis Hauksbee in 1705.

In this experiment Hauksbee placed a bell rung by clockwork in the receiver of an air-pump. So long as the air was not exhausted from the receiver the ringing of the bell was heard distinctly, but as the air became exhausted the sound of the ringing gradually diminished until it entirely disappeared when the vacuum had been produced, although the vibrations of the striker could still be seen. In this condition the sound could be again distinctly heard by allowing a little air to enter the receiver, or by bringing a wire into contact with the bell, the sound waves being conveyed along the wire to the air outside, which then acted as a medium for their transmission.

The appreciation of sounds by the sense of hearing is a function of the brain, and like all such functions can only be vaguely understood. The mechanical arrangement of the ear for receiving impressions of the sound waves, however, is comparatively simple, being the same as the mechanical apparatus made artificially to interpret sound vibration. A thin membrane, like a miniature drum-head, receives these vibrations just as in the case of the membrane or diaphragm used in the telephone receiver, and transfers them to the proper "center" in the brain, where they are interpreted by the sense of hearing. That this drum-head or diaphragm arrangement of the ear acts in accordance with mechanical laws was strikingly shown by an experiment of Bell with his telephone, in which part of one of his earlier instruments was actually made of the human ear.

AN EARLY CONCEPTION OF THE TELEPHONE

The possibility of sending verbal messages at long distances through some other medium besides that of the atmosphere was conceived at least two centuries before the accomplishment of the practical telephone in 1876. In 1667 the English scientist, Robert Hooke, wrote of a method of communication by telephone as follows;

"It is now possible to hear a whisper at a furlong's distance, it having been already done; and perhaps the nature of the thing would not make it more possible, though that furlong should be ten times multiplied. And though some famous authors have affirmed it impossible to hear through the thinnest plate of Muscovy glass, yet I know a way by which it is easy enough to hear one speak through a wall a yard thick.

"It has not yet been thoroughly examined how far otacousticons may be improved, nor what other ways there may be of quickening our hearing, or conveying sound through other bodies than the air; for that is not the only medium I can assure the reader that I have, by the help of a distended wire, propagated the sound to a very considerable distance in an instant, or with as seemingly quick a motion as that of light, at least incomparably quicker than that which at the same time was propagated through the air; and this not only in a straight line or direct, but in one bended in many angles."

Just what Hooke's method of telephoning may have been does not appear. Presumably it was some such arrangement as the string-diaphragm "speaking telephone" to be referred to in a moment. But in any event nothing of practical importance ever came of it.

A step toward the development of a practical telephone was taken in 1819 by Sir Charles Wheatstone who invented what is known as the "magic lyre telephone," by which musical notes were made to respond to similar tones at some distances. But it was not until several years after the invention of the telegraph that any serious attempts were made to perfect the speaking telephone. About 1867, however, a great number of instruments known as "membrane telephones" were put upon the market as toys. This form of telephone, familiar to every schoolboy in his studies of physics, consists of two cups, the bottoms of which are made of a tightly stretched membrane, or parchment, perforated in the middle by a string fastened with a knot at the end, and connecting the two cups. With such an arrangement a person speaking into one of these cups as into the transmitter of a telephone may convey messages a considerable distance to a person holding the other cup to the ear, the string meanwhile being drawn taut. Verbal messages have been sent and received in this way at distances ranging from 150 to 170 yards, but these could only be sent when the string was continuous and not resting against any intervening object. They could not, in other words, be sent around a corner. In 1876, however, Bregnet improved this simple telephone so that it was possible to send a message over a string which made several turns or angles. To do this he inserted little drum-like structures at the turning points of the string, these little drums being made of cylinders with the ends covered by membranes through the centre of which the string passed, thus reproducing the vibrations set up by the voice in the transmitter and passing them along the line to the receiver.

Such telephones, however, were at best only toys for communicating verbal messages a few yards. But at about this time the possibility of utilizing electricity and magnetism for conveying these vibrations to a great distance seems to have occurred to a number of investigators. It had been discovered in 1837 by Page in America that a magnetic bar would emit sounds when rapidly magnetized and demagnetized; and in 1860 Reis had invented a "musical telephone." This instrument was composed of two distinct parts, a sounder and a receiver. The sounder consisted of a sounding-box having across its opening a membrane, in the centre of which there was fitted a small disk of platinum, having above this a metallic point. At one side of the box there was a tube corresponding to a speaking-tube, arranged so as to receive the sound and direct it toward the membrane through the interior of the box.

The receiving instrument consisted of a small iron rod about the size of a knitting-needle placed upon a sounding-box. About this rod was wound an insulated electrified wire, the whole apparatus having the appearance of a long bobbin or a spool of wire fastened upon an ordinary box.

If a musician, stationed before the opening of the tube of the receiving-box, played upon such an instrument as the violin or cornet, the sounds were recorded by the vibrations on the membrane and platinum disk, by means of the point, causing a series of breaks in the current which could be conveyed by wire to the rod and bobbin of the receiver at a considerable distance. By this arrangement various airs and melodies might be heard and distinguished, although it was impossible to distinguish different qualities of tone. That is, while the melody itself could be readily distinguished it was impossible to tell whether the instrument playing was a violin, flute, or cornet. This instrument was not, therefore, a speaking telephone, but simply a "musical telephone," as it was called.

BOURSEUL SUGGESTS AN ELECTRICAL TELEPHONE

In 1854 Mr. Charles Bourseul made the definite suggestion of the possibility of speech being transmitted by electrical means. At that time, although Bourseul's statement was made with scientific knowledge of the subject and by logical deduction based on that knowledge, scientists were not inclined to agree with him as to the possibility of this suggestion in actual practice. This communication, however, had the effect of calling attention to the subject, and paving the way for the invention of the speaking telephone. In his paper Bourseul said, in part:—

"After the telegraphic marvels which can reproduce at a distance handwritings, or even more or less complicated drawings, it may appear impossible to penetrate further into the regions of the marvelous. Yet we will try to advance a few steps further. I have, for example, asked myself whether speech itself may not be transmitted by electricity—in a word, if what is spoken in Vienna may not be heard in Paris. The thing is practicable in this way:—

"We know that sounds are made by vibrations, and adapted to the ear by the same vibrations which are reproduced by the intervening medium. But the intensity of the vibrations diminishes very rapidly with the distance; so that it is, even with the aid of speaking-tubes and trumpets, impossible to exceed somewhat narrow limits. Suppose that a man speaks near a movable disk, sufficiently flexible to lose none of the vibrations of the voice, and that this disk alternately makes and breaks the currents from a battery: you may have at a distance another disk, which will simultaneously execute the same vibrations.

"It is true that the intensity of the sounds produced by means of the voice at the point of departure where the first disk vibrates will be variable and will be constant at the point of arrival, where the other disk vibrates by means of electricity; but it has been shown that this does not change the sounds. It is, moreover, evident that the sounds will be reproduced at the same pitch."

Here was the correct conception, theoretically, at least, of a practical telephone. But Bourseul did not take the necessary steps and construct a practical instrument along the lines outlined in his paper, and the matter dropped out of sight for a decade.

AN INTERESTING COINCIDENCE

Meanwhile the Americans had been making experiments, and on February 14, 1876, Prof. Alexander Graham Bell, of Boston, and two hours later, on the same day, Elisha Gray, of Chicago, each filed in the patent offices at Washington, a *caveat*, or provisional specification, of a practical electric telephone. At the Centennial Exposition in Philadelphia in that year, Gray exhibited a multiplex telegraph, and Bell exhibited his "wonder of wonders," as Lord Kelvin termed that telephone, in addressing the British Association at Glasgow a few weeks later.

"In the department of telegraphs in the United States section," said Lord Kelvin (then Professor Thomson), "I saw and heard Mr. Elisha Gray's electric telegraph of wonderful construction, which can repeat four dispatches at the same time in the Morse code, and, with some improvements in detail, this instrument is evidently capable of a fourfold delivery. In the Canadian department I heard, 'To be or not to be? There's the rub,' uttered through a telegraphic wire, and its pronunciation by electricity only made the rallying tone of the monosyllables more emphatic. The wires also repeated some extracts from the New York papers. With my own ears I heard all this, distinctly articulated through the slender circular disk formed by the armature of an electromagnet. It was my fellow juryman, Professor Watson, who, at the other extremity of the line, uttered these words in a loud and distinct voice, while applying his mouth to a tightly stretched membrane provided with a small piece of soft iron, which executed movements corresponding to the sound vibrations of the air close to an electric magnet introduced into the circuit. This discovery, the wonder of wonders in electric telegraphy, is due to a young fellow countryman of our own, Mr. Graham Bell, a native of Edinburgh, and now naturalized in New York.

"It is impossible not to admire the daring invention by which we have been able to realize with these simple expedients the complex problem of reproducing by electricity the tone and delicate articulations of voice and speech; and it was necessary, in order to obtain this result, to find out the means of varying the intensity of the current in the same proportion as the inflections of the sound emitted by the voice."

DR. GRAHAM BELL DESCRIBES HIS INVENTION

A year later Bell himself described his invention, and the interesting experiments leading up to it, in a paper read before The Society of Telegraph Engineers.

"I hit upon an expedient for determining the pitch which at that time I thought to be original with myself," he said. "It consisted in vibrating a tuning-fork in front of the mouth while the position of the vocal organs for the various vowel sounds were silently taken. It was found that each vowel position caused the reinforcement of some particular fork or forks.

DR. GRAHAM BELL IN NEW YORK COMMUNICATING FOR THE FIRST TIME WITH CHICAGO BY TELEPHONE.

"I wrote an account of these researches to Mr. Alexander J. Ellis, of London. In reply he informed me that the experiments related had already been performed by Helmholtz, and in a much more perfect manner than I had done. Indeed, he said that Helmholtz had not only analyzed the vowel sounds into their constituent musical elements but had actually performed the synthesis of them.

"He had succeeded in producing, artificially, certain of the vowel sounds by causing tuning-forks of different pitch to vibrate simultaneously by means of an electric current. Mr. Ellis was kind enough to grant me an interview for the purpose of explaining the apparatus employed by Helmholtz in producing these extraordinary effects, and I spent the greater part of a delightful day with him in investigating the subject. At that time, however, I was too slightly acquainted with the laws of electricity fully to understand the explanations given; but the interview had the effect of arousing my interest in the subject of sound and electricity, and I did not rest until I had obtained possession of a copy of Helmholtz's great work, and had attempted, in a crude and imperfect manner, it is true, to reproduce the results. While reflecting upon the possibilities of the production of sound by electrical means, it struck me that the principle of vibrating a tuning-fork by the intermittent attraction of an electromagnet might be applied to the electrical production of music.

"I imagined to myself a series of tuning-forks of different pitches, arranged to vibrate automatically in the manner shown by Helmholtz, each fork interrupting at every vibration a voltaic current; and the thought occurred, 'Why should not the depression of a key like that of a piano direct the interrupted current from any one of these forks, through a telegraph wire, to a series of electromagnets operating the strings of a piano or other musical instrument, in which case a person might play the tuning-fork piano in one place and the music be audible from the electromagnet in a distant city?'

"The more I reflected upon this arrangement the more feasible did it seem to me; indeed, I saw no reason why the depression of a number of keys at the tuning-fork end of the circuit should not be followed by the audible production of a full chord from the piano in a distant city, each tuning-fork affecting at the receiving end that string of the piano with which it was in unison. At this time the interest which I felt in electricity led me to study the various systems of telegraphy in use in this country and in America. I was struck with the simplicity of the Morse alphabet, and with the fact that it could be read by sound. Instead of having the dots and dashes recorded upon paper, the operators were in the habit of observing the duration of the click in the instruments, and in this way were enabled to distinguish by ear the various signals.

"It struck me that in a similar manner the duration of a musical note might be made to represent the dot or dash of the telegraph code, so that a person might operate one of the keys of the tuning-fork piano referred to above, and the duration of the sound proceeding from the corresponding string of the distant piano be observed by an operator standing there. It seemed to me that in this way a number of distinct telegraph messages might be sent simultaneously from the tuning-fork piano to the other end of the circuit, by operators, each manipulating a different key of the instrument. These messages would be read by operators stationed at the distant piano, each receiving operator listening for signals of a certain definite pitch, and ignoring all others. In this way could be accomplished the simultaneous transmission of a number of telegraphic messages along a simple wire, the number being limited only by the delicacy of the listener's ear. The idea of increasing the carrying power of a telegraph wire in this way took complete possession of my mind, and it was this practical end that I had in view when I commenced my researches in electric telephony."

Bell then entered into a brief discussion of telephonic currents, with graphic illustrations, and continued:—

"Nine varieties of telephonic currents may be distinguished, but it will only be necessary to show you six of these. The primary varieties designated are 'intermittent,' 'pulsatory,' and 'undulatory.'

"Sub-varieties of these can be distinguished as 'direct' or 'reversed' currents according as the electrical impulses are all of one kind or are alternately positive and negative. 'Direct' currents may still further be distinguished as 'positive' or 'negative,' according as the impulses are of one kind or of the other.

"*An intermittent current* is characterized by the alternate presence and absence of electricity upon the circuit;

"*A pulsatory current* results from sudden or instantaneous changes in the intensity of a continuous current; and

"*An undulatory current* is a current of electricity, the intensity of which varies in a manner proportional to the velocity of the motion of a particle of air during the production of a sound; thus, the curve representing graphically the undulatory current for a simple musical tone is the curve expressive of a simple pendulous vibration—that is, a sinusoidal curve. . . . .

"I have before alluded to the invention by my father of a system of physiological symbols for representing the action of the vocal organs, and I had been invited by the Boston Board of Education to conduct a series of experiments with the system in the Boston school for the deaf and dumb. It is well known that deaf-mutes are dumb because they are deaf, and that there is no defect in their vocal organs to incapacitate them from utterance. Hence it was thought that my father's system of pictorial symbols, popularly known as visible speech, might prove a means whereby we could teach the deaf and dumb to use their vocal organs and to speak. The great success of these experiments urged upon me the advisability of devising methods of exhibiting the vibrations of sound optically, for use in teaching the deaf and dumb. For some time I carried on experiments with the manometric capsule of Koenig, and with the phonautograph of Leon Scott. The scientific apparatus in the Institute of Technology in Boston was freely placed at my disposal for these experiments, and it happened at that time a student of the Institute of

Technology, Mr. Maurey, had invented an improvement upon the phonautograph. He had succeeded in vibrating by the voice a stylus of wood about a foot in length which was attached to the membrane of the phonautograph, and in this way he had been enabled to obtain large tracings upon a plane surface of smoked glass. With this apparatus I succeeded in producing very beautiful tracings of the vibrations of the air for vowel sounds. I was much struck with this improved form of apparatus, and it occurred to me that there was a remarkable likeness between the manner in which the piece of wood was vibrated by the membrane of the phonautograph and the manner in which the *ossiculæ* of the human ear were moved by the tympanic membrane. I determined, therefore, to construct a phonautograph modeled still more closely upon the mechanism of the human ear, and for this purpose I sought the assistance of a distinguished aurist in Boston, Dr. Clarence J. Blake. He suggested the use of the human ear itself as a phonautograph, instead of making an artificial imitation of it. The idea was novel and struck me accordingly, and I requested my friend to prepare a specimen for me, which he did. The *stapes* was removed and a stylus of hay about an inch in length was attached to the end of the *incus*. Upon moistening the *membrana tympani* and the *ossiculæ* with a mixture of glycerin and water, the necessary mobility of the parts was obtained; and upon singing into the external artificial ear the stylus of hay was thrown into vibration, and tracings were obtained upon a plane surface of smoked glass passed rapidly underneath.

"While engaged in these experiments I was struck with the remarkable disproportion in weight between the membrane and the bones that were vibrated by it. It occurred to me that if a membrane as thin as tissue-paper could control the vibration of bones that were, compared to it, of immense size and weight, why should not a larger and thicker membrane be able to vibrate a piece of iron in front of an electromagnet, in which case the complication of steel rods, shown in my first form of telephone, could be done away with, and a simple piece of iron attached to a membrane be placed at either end of the telegraphic circuit.

"The results, however, were unsatisfactory and discouraging. My friend, Mr. Thomas A. Watson, who assisted me in the first experiment, declared that he heard a faint sound proceed from the telephone at his end of the circuit, but I was unable to verify his assertion. After many experiments attended by the same only partially successful results, I determined to reduce the size and weight of the spring as much as possible. For this purpose I glued a piece of clock-spring, about the size and shape of my thumb-nail, firmly to the centre of the diaphragm, and had a similar instrument at the other end; we were then enabled to obtain distinctly audible effects.

"I remember an experiment made with this telephone, which at the time gave me great satisfaction and delight. One of the telephones was placed in my lecture room at the Boston University, and the other in the basement of the adjoining building. One of my students repaired to the distant telephone to observe the effects of articulate speech, while I uttered the sentence, 'Do you understand what I say?' into the telephone placed in the lecture hall. To my delight an answer was returned through the instrument itself, articulate sounds proceeded from the steel spring attached to the membrane, and I heard the sentence, 'Yes, I understand you perfectly.' It is a mistake, however, to suppose that the articulation was by any means perfect, and expectancy no doubt had a great deal to do with my recognition of the sentence; still, the articulation was there, and I recognized the fact that the indistinctness was entirely due to the imperfection of the instrument. I will not trouble you by detailing the various stages through which the apparatus passed, but shall merely say that after a time I produced a form of instrument, which served very well as a receiving telephone. In this condition my invention was exhibited at the Centennial Exhibition in Philadelphia."

BELL VERSUS GRAY

Reference is made in this quotation from Professor Bell's paper to "intermittent," "pulsatory," and "undulatory" currents and the difference in the nature of these currents, and an appreciation of these differences is very important in understanding the working of the speaking telephone. It was an important feature of the controversy between Bell and Gray in settling the question of priority in the invention of the telephone. As explained by Bell, intermittent currents are those interrupted to produce sounds quite instantaneous;

pulsatory currents produce only sounds differing in intensity; while undulatory currents are those which alternately diminish and increase. These last are the currents essential to the modern telephone, and it was largely upon his knowledge of the nature and action of such currents that Bell based his contention of priority over Gray in his intimate knowledge of the actual workings of the telephone.

It will be recalled that the *caveat* sent to the patent office by Bell reached there only two hours before a similar *caveat* sent by Elisha Gray. The patent office, therefore, issued the patent to Bell, although the time between the receipt of the two *caveats* was so short that common justice would demand that both Bell and Gray be considered as equally entitled to the credit of inventing the telephone, provided both instruments described were equally practical. Of course in the mere issuance of the patent, Bell was as legally entitled to his claim as if the difference in time of making the application had been days or weeks instead of hours; but Bell contended, probably with good ground for his contention, that Gray did not at the time understand the importance of what are known as the *undulatory* currents. He did refer to them specifically in his *caveat*, to be sure, but Bell pointed out that the currents thus referred to were really the pulsatory currents and not the true undulatory ones. This, however, is the theoretical and not the practical side of the question. The demonstration that a speaking telephone was a practical possibility was made by Bell and not by Gray, and he must, therefore, go down in history as the inventor of the first practical instrument of this kind.

PRACTICAL IMPROVEMENTS

After Bell's invention became known a host of similar inventions were made. None of these differed in principle, however, from the original telephone invented by Bell. A great number of improvements were made both in the transmitter and receiver of the instrument, but these were purely improvements upon the mechanical application of the principles involved, and not departures from the principle itself.

A great improvement upon the type of receiver was made by Thomas A. Edison; and in 1877 Emil Berliner invented what is known as a microphone transmitter—an apparatus which converts feeble sounds into much louder sounds. By the addition of these two inventions the telephone was greatly improved, and sending and receiving messages at long distance became possible.

Berliner's microphone transmitter consists of a diaphragm with a metal patch in the centre. Against this a metal knob is pressed lightly by an adjusting-screw, the result of this arrangement being an apparatus which greatly magnified the sound effects.

Three months after Berliner produced his microphone transmitter, another instrument designed for a similar purpose was invented by Edison. This consists of a diaphragm having a platinum patch in the centre for an electrode. Against this a hard point, made of plumbago and vulcanized rubber, is pressed by means of a long spring, the amount of pressure being adjusted by a screw near the base. This transmitter worked admirably, and, as improved by the inventor shortly after, constituted an excellent and practical instrument. Other transmitters were invented by Professor Hughes and Francis Blake, the Hughes transmitter being the popular one in Europe, while the Blake transmitter came generally into use in America.

Within the last few years what is known as the long-distance telephone, connecting points at a distance of a thousand miles or more, has been perfected. This does not differ in principle, of course, from the ordinary telephone, the difference being represented largely by the material used in the conducting wires. For short distances the ordinary iron wire answers all practical requirements; but this material is a relatively poor conducting medium, and copper, being a much better conductor, is necessary for long-distance telephones.

In addition to this improvement in the conducting medium it has been found necessary to increase the sensitiveness of the transmitter in long-distance telephones. For, unlike the telegraph, no practical system of relays for strengthening the current has been perfected as yet, although the limit of long-distance telephony is greatly increased by inserting self-induction coils at intervals along the line.

The first long-distance transmitter was what is known as the Hunnings' transmitter. This consists of a shallow vertical box with insulated sides, and a metallic back and front. The front of the box is made of very thin metal and acts as a diaphragm, the interior of the box being filled loosely with hard carbon granules. The current from the battery passes from the diaphragm through the carbon granules to the back of the chamber, the vibrations of the diaphragm causing vigorous vibrations of the granules, thus producing long sounds. A modification and improvement of this chamber has been made by A. C. White in America, and this is the transmitter, known as the "solid back" transmitter, now in general use on long-distance telephones in the United States.

TELEPHONE EQUIPMENT

The question of equipment and operation of telephones over any amount of territory large or small, is one that is constantly occupying the attention of engineers, as the almost universal use of this instrument renders even the slightest improvement in the facility and directness of communication a matter of the greatest importance to both the public and the telephone companies.

"Three distinct types of telephone equipment have been developed," explains a recent writer in the *Electrical Review*, "the magneto or local-battery, the common-battery or lamp-signal, and the automatic system. The first two may be further subdivided into the transfer and the multiple systems. . . .

"The trunking or transfer system is a development of the original transfer system. It is due to an effort to meet the increasing demands of the rapidly growing telephone systems. In the early days of telephones, when there were but few subscribers, but more than one operator could take care of, the calls were transferred from one operator to another by what was known as a transfer. Later, the multiple switchboard was devised, thus eliminating the transfer. Now the still greater increase in number of telephones has carried the capacity beyond that of the multiple switchboard, thus making necessary the establishment of branch exchanges with trunk connections."

The growth of the telephone has been such that in the larger cities a great many exchanges have been found necessary. In the five boroughs of New York city, for example, there are at the present moment (1910) fifty-seven exchanges in operation, and new ones are constantly being established. It is obvious, therefore, that under these conditions, the multiple switchboard is no longer the most economical form of equipment, since the large majority of a subscriber's calls will probably be for a station other than his own.

Hence in large cities it has become the practice to do away with the subscriber's multiple switchboard at his own exchange, and treat every call as a "trunked" call. This method has proved expensive both in first cost and operation, and out of it a system, technically known as the "semi-automatic," has been developed, which eliminates a considerable number of the operators necessary in the manual system, and does not require the intricate mechanism of the automatic. It can be installed wherever the lamp-signal equipment is employed. Briefly, it may be described as follows:

"A subscriber, upon lifting his receiver from the hook, operates in the main office a line-relay similar to that used in the modern lamp-signal board, but this, instead of lighting a line-lamp, energizes a simple selector-switch which selects an operator who is not busy and, in turn, selects a connecting cord which is not busy, and lights the lamp associated with this cord. The current lighting this lamp passes through a low-wound relay, which connects the operator with the subscriber. Upon receiving the number of the instrument wanted, the operator inserts the plug in the multiple, and rings. Upon inserting the plug in the jack, the cord-lamp is automatically extinguished and the operator's listening-set is disconnected at the same time, leaving the two subscribers to converse in privacy."

Automatic telephone systems, which dispense with manually operated central exchanges, are installed and working satisfactorily in many places throughout the United States at the present time. They are particularly popular in the Middle West, Chicago having such a system with over ten thousand subscribers. The system works perfectly for short-distance messages—such, for example, as in the urban service or between a large city and its suburbs—but it is not adapted to long-distance communications.

The telephone instrument itself resembles the ordinary wall-piece, with bells, receivers, and transmitters, but in addition has what is known as a "calling-dial." This is a circular metal piece, near the edge of which are ten finger-holes, numbered from 0 to 9. When a subscriber wishes to call up anyone he removes the receiver, and turns the dial so that the finger-holes corresponding to the digits of the number he is seeking are brought in succession to a certain point on the rim of the dial. For example, if he wishes to call 973 he first turns the "9" finger-hole to the stop on the indicator and allows it to return to its normal position, doing the same thing successively with the figures 7 and 3. He then pushes a button, which rings the bell of the person wanted. If the 'phone he wishes to call is busy at the time a peculiar buzzing sound notifies him that such is the case.

THE WIRELESS TELEPHONE

The advantages of a system of telegraphy that does away with wires are too obvious for discussion, yet any system of communication whereby messages must be spelled out slowly by means of dots and dashes is manifestly inferior to a system of enunciated words, such as telephonic communications.

When Marconi and his associates in experimental wireless telegraphy set at rest forever all doubts as to the possibility of electric communication through the air by means of the Hertzian waves, they removed at the same time all doubt as to the possibility of eventually accomplishing spoken communications through space in a similar manner. In theory, at least, it should be possible to send wireless telephonic messages as well as

MESSAGES BY WIRELESS TELEGRAPH AND WIRELESS TELEPHONE.

The upper figure shows an operator receiving a wireless message from across the ocean. It will be seen that he actually receives the message with the aid of a telephone. The lower figure represents the simple apparatus used in sending and receiving messages by the wireless telephone. "Wireless" is in a sense a misnomer in each case, since wires are necessarily used at sending and receiving stations. Once under way, however, the messages are transmitted through the ether, independently of any material substance.

telegraphic ones. But it took many years of study and experiment before the marvel was actually accomplished. In round numbers the practical wireless telegraph preceded the wireless telephone by a decade.

In point of practical accomplishment, American inventors have shown the way in the development of wireless telephony, as they did half a century earlier in telegraphy. And as the name of Morse must always be associated with telegraphy, so the name of Dr. Lee DeForest, a native of Western America, will always be linked with practical wireless telephony. In 1907, Doctor DeForest built his first instruments and transmitted the music of a phonograph a few blocks to a receiving station in New York. A few weeks later he was able to report by voice the results of yacht races a distance of about four miles. In the autumn of the same year his instruments were installed on the ships of the American fleet of war-vessels on their trip around the globe, and kept those vessels in verbal communication with each other, in storm and calm, during the entire voyage. A year later messages had been sent and received a distance of over five hundred miles, and a practical working-service between Chicago and Milwaukee put into operation.

Theoretically there is very little difference between the wireless telephone and the one requiring connecting wires. The vibrations of the voice, in each instance, affect a disk which releases electrical impulses of varying degree. In one case the speaker transmits his voice along a wire, in the other through the air, just as he might shout to a friend a block away, with this important difference, that by means of the radiophone the sound of his voice may be hurled miles instead of feet.

The sending instrument first used by Doctor De Forest, and which may be taken as the model for succeeding instruments, consists of an ordinary microphone transmitter, in which the various vibrations caused by the voice affect the intensity of an electric current. The ether is made to receive a continuous chain of impulses caused by a rapidly vibrating arc light—Dudell's arc, as it is called. The oscillations of this arc light are modified in accordance with the variations of the voice as it causes fluctuations of the microphone current. These impulses affect the circuit of the receiving apparatus, modify it, and the current so modified passes through the filament of an incandescent lamp, causing the light to vary in accordance with the original vibrations. The variation of the light causes constant changes in the conducting power of the air remaining in the bulb. This rarefied gap in the lamp is used in place of a wire for completing the circuit of a telephone receiver, the varying current causing the receiver to emit sound waves just as the wire telephone does.

In some of the more recent instruments there is an oscillating arrangement by means of which electrical impulses are constantly sent out at a tremendous rate of repetition. This causes a faint humming in the receivers, altogether too slight to be annoying to the listener. The vibrations of the voice cause lapses or breaks in the oscillating impulses, this arrangement increasing the efficiency of the instrument over those in which the vibrations of the voice-impulses are sent forth. The scientific explanation of why such an arrangement is more efficient, is so complicated as to mean little to the average layman. A recent writer explains it by metaphor as follows:—

"Imagine a man standing on the bank of a small pond, throwing bricks into the water. These create big waves at broken intervals which can be managed to convey signals of a code. That is the old spark of telegraphy.

"Now, instead of a man with bricks, picture a huge funnel containing sand, which allows one grain at a time to fall to the water at a high rate of speed. The waves sent forth are barely perceptible, but are none the less existent. Each time the man wants to send a signal or impulse he shuts off the flow of sand. He can do this with infinitely greater speed than the man can throw bricks. Hence it follows that the number of waves or impulses transmitted in a given time is only limited by the grains of sand that can be dropped. Results are convincing. Under the old system about forty words a minute could be transmitted. Under the new, 40,000 words an hour are possible, could they be sent so rapidly."[1]

The infinite advantage of wireless over wire telephones has been demonstrated recently on many occasions. Storms and accidents of all kinds are forever putting connecting wires out of commission, completely isolating whole regions for hours or even days at a time. Even submarine cables have the advantage over ordinary terrestrial wires in this respect. A few years ago a Boston correspondent of a New York paper, who was reporting a murder trial of considerable notoriety, found that a severe snow-storm had destroyed all telegraphic and telephonic communication with the metropolis, thus blocking him and his brother reporters in their daily stories. In this extremity a brilliant idea occurred to him. The cables to Europe were working as usual. By sending his story to New York by cable via London this keen-witted correspondent accomplished a "scoop" that is now newspaper-reporter history. To-day he would have done the same thing via wireless telephone or telegraph. But it would have been no "scoop." For every other reporter would have done the same thing, many of them as an ordinary routine.

One advantage of the wireless telephone over the wireless telegraph is the fact of its compactness. A good working instrument can be made small enough to be carried in a coat pocket. In this day of air-ships, where every superfluous ounce of weight is dispensed with, the compactness of the wireless telephone makes it doubly valuable. It adds practically nothing to the weight of the car, and yet it affords a means of constant communication between the air-ship and distant points. It is declared by many serious thinkers that the development of the wireless telephone plays a most important part in the development and practical usefulness of the air-ship. But this is only one of a thousand important applications of wireless telegraphy.

V

THE EDISON PHONOGRAPH

IF a popular vote were to be taken to decide what invention was considered the most wonderful of all those produced during the latter part of the nineteenth century, it is probable that the majority of votes would be cast in favor of the phonograph. The *X*-ray apparatus for photographing through opaque substances, and the telephone, would surely come in for a large vote. But to most persons, nothing quite so much approaches the realm of the miraculous as the little instrument, small enough to be carried in a good-sized coat pocket, which reproduces accurately all manner of sounds from violin notes to steam sirens.

It seems superfluous to say that the inventor of this marvelous instrument is Thomas A. Edison. The name "Edison phonograph" has become generic as well as descriptive.

On the 31st of July, 1877, Edison first applied for a patent on his "speaking phonograph." It was by no means the first instrument ever made upon which words could be recorded. Even as early as 1856, Mr. Leo Scott produced what was known as a "phonautograph"—an instrument so arranged that the vibrations made by sounds were recorded on smoked glass, or some other similar substance, by means of a needle attached to a diaphragm. This instrument worked perfectly in simply recording sounds; but it did not reproduce these sounds, and apparently the inventor made no attempts to do so. His claim to priority in inventing a speaking phonograph, therefore, is absolutely groundless. A more reasonable claim might have been made by the Frenchman, M. Charles Cros, who, in April, 1877, sent to the Academy of Science, in Paris, a paper describing the way in which an instrument might be made that would reproduce such sounds as the human voice. But this was simply a description of a possible instrument, the actual construction of which had not been attempted. And when Abbé Leblanc, a short time later, constructed an instrument after the method described by Cros, it failed utterly as a sound-producer. It is evident, therefore, that Edison's claim to the invention of the first phonograph stands absolutely unchallenged.

In contrast to the wonderful effects that may be produced by this instrument is the simplicity of the construction of the instrument itself. The Edison phonograph of 1877 was fitted with a cylinder covered with tin-foil for receiving the impression of the sound waves. This cylinder was so arranged that, as it revolved, it moved at a definite rate of speed from right to left, this movement being controlled by the action of screw threads. Above this cylinder, and arranged so that a needle point pressed into the tin-foil, was the recorder. This consisted of a cylinder about two inches in diameter, over the lower end of which was stretched a diaphragm of parchment or gold-beater's skin, with a needle or recording point fastened to the centre. When sounds were projected into the upper end of the cylinder the vibrations thus set up caused the diaphragm to vibrate back and forth. This vibration, producing upward and downward movements of the needle, caused it to make indentations on the rotating cylinder of tin-foil beneath, recording precisely the vibrations made by the sounds in the cylinder. These sounds could then be reproduced by setting back the cylinder and rotating it at the same rate of speed as before, causing the needle to pass over the indentations in the grooves made while recording, thus reproducing the vibrations of the diaphragm. This was the principle of Edison's first phonograph, and this is the underlying principle of his own later perfected instruments as well as of all other forms of "talking machines," although the details of the operating mechanism have been greatly modified.

Between 1877 and 1888 Edison was constantly making improvements in his invention until he had perfected the phonograph practically as we know it to-day. In the newer instruments the parchment diaphragm of the older instrument has been replaced by a thin glass plate; and the cylinders are no longer made of tin-foil but of a dark-brown waxy substance familiar as phonograph "records." Clockwork or electricity has been applied for rotating the cylinder, so that the old winding movement of the crank is now done mechanically.

A great improvement has been made in the pointed marker or recorder, and the corresponding instrument for reproducing the records. In place of the steel needle used on the first instruments, the marker is now made of a small piece of sapphire with a chisel-shaped edge, while the point used in reproducing the sounds is also made of sapphire with its edges rounded and of a peculiar shape. The shape of this little point is very important, as clear reproductions are largely dependent upon its construction.

The advantage of the wax cylinders over those made of tin-foil is that they are more permanent and may be duplicated by molding an indefinite number of times. Furthermore they record sounds readily and reproduce them better.

For reproducing sounds three things are necessary in the shape and arrangement of the indentations in the grooves made by the recorder. It will be recalled that the pitch of any sound depends upon its number of vibrations per second—sounds of a high pitch or frequency having more vibrations than those of a low pitch. On the cylinder, therefore, a high note is recorded by a certain number of indentations in a given space, while low notes have a correspondingly less number. The number of indentations is quite independent of the loudness of the sound to be reproduced; this is controlled by the depth of the indentations made, a loud sound producing deep indentations while softer sounds are represented by shallow ones.

The fact that these little indentations will reproduce sounds seems wonderful enough to the ordinary mind, but the real wonder lies in the fact that qualities of sounds are also reproduced in the little grooves—the violin, for example, being almost as easily distinguishable from the French horn as it is in the orchestra itself.

This quality of sound is reproduced by the form of the indentations in the wax, regardless of their frequency or depth. When it is considered that all the complicated vibrations determining pitch, loudness, and quality of sounds, are recorded by minute, almost microscopic, indentations in little grooves scarcely perceptible to the naked eye, it is little wonder that the Edison phonograph remains a constant source of marvel.

In the issue of the *North American Review* for May–June, 1878, Edison described his then recent invention, and recorded some of the prophecies as to the possibilities of its use in the future. He said in part:—

"The apparatus now being perfected in mechanical details will be the standard phonograph, and may be used for all purposes except such as require special form of matrix, such as toys, clocks, etc., for an indefinite repetition of the same thing. The main utility of the phonograph being, however, for the purposes of letter-writing and other forms of dictation, the design is made with a view of its utility for that purpose.

"The general principles of construction are a flat plate or disk, with a spiral groove on the face, worked by clockwork underneath the plate; the grooves are cut very closely together, so as to give a great total length to each length of surface—a close calculation gives as the capacity of each sheet of foil nearly 40,000 words. The sheets being but ten inches square, the cost is so trifling that but a hundred words might be put on a single sheet economically.

"The practical application of this form of phonograph is very simple. A sheet of foil is placed in the phonograph, the clockwork set in motion, and the matter dictated into the mouthpiece without other effort than when dictating to a stenographer. It is then removed, placed in a suitable form of envelope, and sent through the ordinary channels of correspondence to whom it is designed. He, placing it upon his phonograph, starts his clockwork, and *listens* to what his correspondent has to say."

It will be seen that even at this time Edison foresaw clearly the future that was in store for his invention. And the significant part of his statement, foreshadowing the use of phonographs in dictating letters and documents, is now put in practical every-day use by thousands of persons all over the world. The cylinder records, however, are not used as Edison suggested—that is, sent through the mails in special cases or envelopes—but are turned over to typists who record the dictation on typewriting machines in the ordinary manner. This is but one of the many ways in which the phonograph has proved itself a most useful invention. But even without this important commercial value, the instrument affords a means of harmless amusement and entertainment of no small significance in the healthful development of a community.

VI

PRIMITIVE BOOKS

IN considering the work of ancient scribes, one is met at the outset with the curious fact that it is somewhat difficult to say just what constitutes a book. We may assume, however, for the present purpose, that a book is any written or printed document, more extensive than a mere letter, intended to convey information from one person to another. Our first concern will be with the primitive types of books. Making a very bold and general classification, there may be said to be five of these, namely, first, the papyrus roll, as used by the early Egyptians; second, the tablet of baked clay; third, the prism or cylinder of the same material, used by the Babylonians and Assyrians; fourth, the palm-leaf type, as employed by the Hindus and their followers of the Far East; fifth, folded books.

It is perhaps impossible to say with certainty which of these types is the most primitive. The oldest books in existence are, doubtless, those of the Babylonians; but the great permanency of these is explained by the material of which they are composed, and it does not follow that they were necessarily the first books to be made. We know that the Egyptians employed a papyrus roll from the earliest historical periods, and that the Hindus made their palm-leaf books at a very early day. In short, every civilized nation is discovered, at the very dawn of its history, in full possession of a system of book-making; each nation having, seemingly, acted under the stress of necessity in selecting a material made accessible by its surroundings.

It is equally impossible to decide the question as to whether one nation borrowed from another in developing the idea of book-making. The diversity of material does not suggest such borrowing, and it would seem that such widely separated nations as, for example, the Aztecs of Mexico, the Egyptians, and the Hindus, could not greatly have influenced one another, unless, indeed, the origin of books dates back to a period when all of these nations were still members of the same prehistoric body politic,—a supposition which is not altogether gratuitous, but which carries us too far into the realm of conjecture to be pursued further here.

Limiting our view strictly to the historic period, we find, as has been said, the five types of books in general use. We have now to consider briefly the distinguishing characteristics of each of these types, before going on to note the steps of development through which the modern book was evolved. First let us give attention to the papyrus roll of the Egyptians. As has been said, this type of book was employed in Egypt from the earliest day of the historical period. As is well known, papyrus is a species of primitive paper—the word paper being, indeed, a derivative of papyrus—which was made of stalks of the papyrus plant placed together to form two thin layers, the fibers of one crossing those of the other, and the whole made into a thin, firm sheet with the aid of glue and mechanical pressure. The strips of papyrus were usually from eight to fourteen inches in width, and from a few feet to several yards in length. This scroll was not used, as might perhaps have been expected, for the insertion of a single continuous column of writing. A moment's consideration will make it clear that such a method would have created difficulties both for the scribe and for the reader; therefore the much more convenient method was adopted of writing lines a few inches in length, so placed as to form transverse columns, which followed one another in regular sequence from the beginning to the end of the scroll. Each column was therefore closely similar, in size and appearance, to the page of a modern book. It will be seen that such a scroll could be read conveniently by rolling up one end as fast as the other was unrolled, the process, however, requiring the use of both hands. When not in use, the book formed a compact roll convenient either for carrying about or for storing on a shelf.

That this form of book had great practical merits is shown by the fact that it was adopted by the Greeks and Romans. Parchment was the substitute for papyrus as material for the roll, but the form of the book itself was not changed, in any essential, throughout the classical period. All of the Greek and Roman books consisted of such rolls, and this, presumably, was the form also in which the Hebrew writings were first given to the world. It will be recalled that the classical writers usually divided their works into so-called books of comparatively small extent. Thus the History of Herodotus, as everyone knows, is divided into eight books.

It is probable that, originally, each book occupied a single papyrus, or parchment, roll, and that the division into books was originally suggested for mechanical convenience to avoid too large a roll. A single work—what we should call a single volume—thus consisted, ordinarily, of several parchment, or papyrus, rolls.

TERRA-COTTA BOOKS OF THE BABYLONIANS AND ASSYRIANS

Since the papyrus roll was so convenient and so extensively used, there can be little doubt that it made its way, at one time or another, to Mesopotamia, the home of the Babylonians and Assyrians, who were so long the greatest rivals of the Egyptians. This supposition is more than an inference, for the sculptures of the Assyrians show their scribes making records upon what appear to be scrolls of some flexible material. It seems tolerably certain that no traces of books of this character have been preserved in Mesopotamia, the explanation being that the climatic conditions are very different there from those existing in Egypt. Even had the Babylonians used papyrus habitually, it is highly improbable that a single scrap of this material would have been preserved to the present time. The fact that no books of the classical period have been preserved in Greece or in Italy, with the single exception of a library in the buried city of Herculaneum, gives full explanation of the absence of papyrus books from the Babylonian tumuli.

But, on the other hand, it is highly probable that the

Babylonians and Assyrians were never altogether converted to the use of the Eygptian form of book, and that, from first to last, they used of a preference the one which is so characteristic of their civilization, and of which tens of thousands of specimens have been preserved; namely, the tablet, or cylinder, of baked clay. These tablet books first came to the eye of modern scholarship through the excavations that were made at the site of old Nineveh by the Frenchman Botta, and a little later by Sir Henry Layard, about the middle of the nineteenth century. The most important collection that early investigations of Layard brought to light was found in the ruins of the library of the famous Assyrian king, Assurbanipal. This collection had peculiar interest because it contained, among other things, the fragments of the sacred books of the Babylonians and Assyrians, including creation and deluge stories somewhat closely akin to those of the Hebrews. Subsequent explorations revealed vast quantities of similar books in the ruins of much older cities than Nineveh, in particular at Nippur, one of the oldest cities of Babylonia, where the famous researches of the University of Pennsylvania have been carried out, and where many thousands of tablets in a single collection have been discovered.

All these tablets are by no means entitled to be called books, many of them being mere business documents, such as bills of sale, records of loans, and the like. But others of the tablets preserve the text of literary documents precisely comparable to modern books. The tablets are usually oblong in shape. The usual size is perhaps three or four inches in width by five or six in length and half an inch to an inch in thickness. Each tablet is complete in itself, constituting virtually the leaves of a book, but there are no means of holding these leaves together. They were merely piled one upon another on the shelves of the library. As an aid to the reader, an expedient was adopted which the printers of modern books invented, independently, some thousands of years later, and which has only recently gone out of vogue; the expedient, namely, of repeating at the foot of each page the first word of the next.

The writing upon the clay tablet was done with a sharp curved implement, which readily made the little arrow-shaped stroke which is the foundation of the Babylonian script. The deftness and regularity with which these so-called cuneiform inscriptions were made, has been the amazement of all modern scholars who have studied them. Notwithstanding the relative perfection of execution, however, these inscriptions are extremely difficult to decipher. This is particularly true of some of the smaller tablets where the character is very small. It will be understood, of course, that the inscriptions were made on these tablets while the clay, of which they were composed, was in a soft condition. The tablet was subsequently either dried in the sun, or baked in an oven, becoming a brick of almost imperishable hardness. This, of course, accounts for the preservation of the vast quantities of Babylonian and Assyrian records. Thanks to the imperishable material of these books, the present-day student of ancient history is gaining a more direct and specific knowledge of oriental history than we shall, perhaps, ever be able to obtain regarding much more recent classical periods. For, as already pointed out, the Greeks and Romans made their records chiefly on perishable materials.

In addition to the flat tablet, the Babylonians and Assyrians wrote some of their books on large prisms and cylinders. Some of these cylinders are as much as two feet in length, and eight to ten inches in diameter. Being made of the same material as the tablets, they are necessarily heavy and cumbersome, yet they were in some ways more convenient for reading, since they were perforated longitudinally, and placed on a spindle, so as to revolve. In some cases the writing runs from end to end of the cylinder, which is then suspended horizontally. In other cases the cylinder is upright, the columns running from top to bottom. In the latter case, the book is usually not a true cylinder, but a prism of six, eight, or ten sides, each side holding a separate column of writing like the page of a book. These prisms and cylinders were commonly selected by the kings to contain records of their deeds. Thus the British Museum contains prisms on which are recorded achievements of such famous conquerors as Sargon, Sennecharib and the Elamite warrior, Cyrus. The last-named cylinder has peculiar interest because it describes the taking of Babylon. There is also a cylinder of King Nabonidus, the ruler of Babylon, which contains another account of the same transaction. It appears that Nabonidus capitulated to Cyrus, and that there was no such scene of carnage as the

Hebrew imagination has pictured in connection with the fall of the famous city. Neither was there a King Belshazzar in Babylon at this, or at any other time. King Nabonidus, however, had a son named Belshazzar who probably served in the army and whom the Hebrews probably confused with his father, as they also confused the capture of Babylon by Cyrus with its subsequent capture by Darius. The oriental mind was, and is, curiously defective in its conceptions of the necessities of exact history.

THE PALM-LEAF BOOKS OF THE HINDUS

The examples of the Egyptians and Babylonians illustrate the fact that the material selected for bookmaking depends upon natural conditions of the environment. So when we go still farther to the East, it is not surprising that we find the knowledge of the Hindus recorded on books of a quite novel character. The type here is a peculiar form of palm leaf, two or three inches in width, cut in sections of a convenient length, say from one to two feet. Such strips of palm leaf afford a convenient surface for receiving the writing, and they have the merit of requiring no preliminary treatment beyond mere drying. Each strip is comparable to the leaf of a book, the writing, as usual, being placed upon it longitudinally. The leaves are then piled upon one another in sequence. Sometimes they were perforated at each end and strung together like Venetian blinds.

This principle of long, relatively narrow leaves, inscribed on only one side and piled together to make a book, was adopted everywhere in the Far East. The palm leaf was the model, as just suggested, and it continued a favorite medium; but, in course of time, various nations, perhaps finding it difficult to secure the native material, imitated it with various artificial mediums. Thus the sacred books of the Buddhists in India itself and in Burma are sometimes written on strips of gold, wood, or of ivory, and the books of Tibet, though retaining the essential character of the palm-leaf book, are inscribed on what is virtually a form of paper. Even cloth was sometimes made to serve the same purpose.

It will be obvious that this palm-leaf type of book has many elements of convenience. It is light and portable, unlike the Babylonian book which it resembled in appearance, and it is certainly more easy to manage in reading than the papyrus roll of the Egyptians. To handle the palm leaves is virtually equivalent to turning the leaves of a modern book, and it seems odd that some inventive Hindu did not hit upon the idea of fastening the leaves together at one end, leaving the other free. Had this been done, the type of the modern European book would have been invented.

FOLDED BOOKS

A much nearer approach to the form of the modern book was made by an obscure nation called the Battaks, who inhabited the Island of Sumatra. This people invented, or adopted from some unknown source, a form of book consisting of a long strip of thin bark, five or six inches in width, and therefore closely resembling a strip of Egyptian papyrus. The writing of the Battak —usually ornamented with pictorial designs—was placed in transverse columns on this strip, precisely after the Egyptian manner. But they make a fundamental innovation in the art of book-making, for the Battak, instead of rolling his strip of bark in the simple Egyptian manner, folded it into accordion-like pleats; so that it took precisely the form of a modern book with leaves uncut at the edge, each column of writing forming a single page. Wooden covers were then put on either side of the book, the whole being sometimes bound together with a piece of snakeskin. Had the Battak scribe gone one step further by cutting the leaves of his book and writing on both sides, we should have had the exact prototype of the modern European book. But, notwithstanding the obvious economy of material that this expedient would have brought about, there is no evidence that any Battak scribe ever utilized this idea. So the Battak book, though standing one step nearer to the modern form, is still imperfect.

Curiously enough, the Aztec Indians of Mexico were found in possession of books precisely of the Battak type when the Europeans first invaded their territory. The material of these Aztec books was a kind of paper, so the Americans had, in this regard, advanced upon the Battaks; but the leaves of these books, like the others, remained uncut so that half the writing surface was still wasted.

We have now to inquire how, and when, the final step in the mechanical art of book-making was taken.

Notwithstanding the wide diversity of materials of the various books that we have examined, it appears there is one interesting peculiarity in which they all agree; without exception they are written upon one side of the leaf whether that leaf be a papyrus roll, a slab of clay, or a palm leaf with its various artificial modifications. The cylinder of the Babylonian might, indeed, be named as an exception, since here the entire available surface is utilized. But as this unique form of book had no successor, it may be disregarded for the present purpose. As to all the others, it is obvious that half the available writing surface of the material used is wasted. The extravagance of this method must have been obvious to the ancient scribes, particularly when it chanced that papyrus and parchment were difficult to secure. The fact that the backs of papyrus rolls were often used to receive odd bits of writing, such as memoranda, personal accounts, and the like, is in itself proof that the matter received attention, but it is equally clear that the manner of rolling a book left the outer surface too much exposed to make its regular use feasible. Nor did the Egyptian ever change his method in this regard. Perhaps the abundance of papyrus plants, and the relative ease of securing book material, withheld the stimulus that might otherwise have led to invention. But, outside of Egypt, this stimulus made itself felt with sufficient vigor. In the time of the Seleucids, the inheritors of Alexander's empire in western Asia found it very difficult to secure papyrus, and were forced to the use of parchment which was said to have been invented at Pergamus, but which was probably only perfected there, since a statement of Herodotus makes it clear that the use of skins in writing had been practised long before. In any event, parchment eventually superseded papyrus as a book material everywhere in the Western world, outside of Egypt. It continued to be almost the exclusive book material everywhere in Europe until paper was invented, late in the Middle Ages.

It must be obvious that parchment, being made of specially prepared skins of animals, is a much more costly material than papyrus. In point of fact, it became very costly indeed in the Middle Ages, and, in securing it, the scribes of the time were often put to their wits' end. Here, then, was the traditional stimulus to invention—necessity. The unmarked outer surface of this parchment roll must have persistently appealed to the eye of even the least inventive scribe, and we can little doubt that many a writer was led to utilize this surface, even while the form of the book still remained a roll. It must be added, however, that this is an inference only, for no rolls written on both sides have been preserved to us: a fact sufficiently explained by the almost total loss of the earliest examples of European book-making. The oldest parchment books that are preserved date only from the third or fourth century, A. D., at which time the folded book, with writing on both sides of the leaf precisely as in the modern printed book, had made its appearance.

By what steps had this transition from the roll to the folded book been accomplished? We can only guess.

A natural inference, based on the observation of the Battak and Aztec books, would be that some one was led to adopt the same plan of folding the parchment scroll, which we have seen in vogue amongst these nations, and that the constant wearing away of the edge of such a book, with the consequent exposure of the unused surface, forced new possibilities upon the attention. But it is always futile, in such a case as this, to attempt to reason from effects back to causes. Things seem so easy after they are done, that it is more natural to accuse our predecessors of stupidity for their delay rather than to give them credit for their invention. And in this particular case, it seems so natural a thing to use both sides of a sheet of paper in writing, that one can hardly avoid wondering at the conservatism of the many generations of the scribes of antiquity who wasted half their writing material.

But whatever the exact stages of transition, the folded book with cut leaves, inscribed upon both surfaces, the said leaves fastened together at one edge and bound into a volume almost precisely like a modern book, had fully established itself in popular usage by the third or fourth century of our era. Since that time there have been numerous minor modifications or shifts of fashion in book-making, but the essential principles of the mere mechanics of the art have not been modified. When, in the fifteenth century, the printing-press began to supersede the old-time scribe, there was no question of inventing a new type of book; the whole thought of the makers of printing-presses was merely how to adapt their machinery to the form of book which custom had sanctioned for many centuries; which, as we know, it still sanctions. If this form of book lacks anything of perfection, no one has, as yet, pointed out a plan for its betterment.

THE TEXT OF ANCIENT BOOKS

Thus far we have considered the book as a mechanical contrivance for the reception of writing. We have now to turn attention to that really essential feature, the writing itself. Here, again, it is the mechanics of the subject that will generally claim our attention. That is to say, we shall disregard questions of philology and of systems of writing, and call attention merely to certain peculiarities that were common to all the different systems, and the fact that these may be considered as characterizing certain peculiarities of the mental development of our race. Our inquiry will have to do with such practicalities of writing as the direction of the script, questions of the division of words, the punctuation of sentences, capitalization, and paragraphing. All of which convenient accessories seem fundamentally essential to us, but none of which was utilized by the earliest makers of books.

An examination of any ordinary scroll of Egyptian writing will show that the figures of birds, animals, and men all face in one direction. In some scrolls they are all turned to the right, and in others all to the left, and, as a rule, the same plan holds throughout any single piece of writing. The explanation of this is that the Egyptian writing is always to be read from the direction toward which the figures face, and that no uniformity existed in practice as to which direction that should be. It appears to have been a matter of indifference to the Egyptian scribes and readers whether they wrote and read from right to left, or from left to right. It would seem as if convenience would have established the custom in favor of one direction or the other, but such seems not to have been the case.

With the Babylonians, however, such a custom of writing always in one direction had been early inaugurated. The character of the Egyptian writing, which consisted essentially of drawing pictures, made it perhaps equally convenient for the scribe to write in either direction. But this was not the case with the Babylonian and Assyrian writing, which, being made rapidly with the aid of a small stylus, could be much more conveniently carried forward from left to right—assuming the scribe to be right-handed—than in the opposite direction. Hence the method of writing from left to right gained universal prevalence. This method, as everyone knows, has the sanction of all European nations to-day. It is also used by the Ethiopians, but, curiously enough, it is not employed by such nations as the Arabians and Turks, who are of the racial stock of the Babylonians, nor by the Persians. Nor did the earliest Europeans adopt this direction of writing without cavil. Some of the oldest Greek and Roman inscriptions show a departure from any oriental model in that the writing runs in opposite directions in alternate lines, leading thus backward and forward across the page, in a way which suggested to the Greek mind the alternate furrows of a ploughed field, and which, therefore, received the name of the *boustrophedon* or—in an awkward literal translation—oxwise. This plan had certain conveniences. The immediate contiguity of the end of one line with the beginning of the next makes it easy for the eye to follow on without danger of skipping. The reversed character of the letters and words of each alternate line is a little puzzling at first, but presents no difficulties to the practised eye. It is, at least, open to question whether this method might not have been adopted for the printed page, particularly where the lines are long, with distinct advantage. Be that as it may, however, the ancient scribe decided against the plan in course of time, and *boustrophedon* writing appears to have gone out of vogue altogether at least four or five centuries before the beginning of our era.

It seems so natural for us to write from left to right, that the selection of this direction in preference to the other seems to call for no explanation. If explanation were required, the fact that the majority of scribes are right-handed seems an all-sufficient one. Yet, the equally familiar fact that the vast literature of Arabia, Turkey, and Persia, has been a continuous writing in a flowing script that runs from right to left, robs this explanation of its plausibility, unless, indeed, it can be shown that the oriental scribes are either ambidextrous, or left-handed; a suggestion for which there is, apparently, no evidence. Whatever the motives actuating the selection, the fact remains that oriental writing as a rule is inscribed from right to left, occidental, uniformly from left to right, and that each finds its prototype in the varied scripts of old Egypt.

As regards the incidental aids to reading supplied by the separation of words from one another, the use of punctuation marks, of capitals, and of division into paragraphs, ancient writings, with very few exceptions, show a striking uniformity. To each and all of them, these expedients are quite unknown. The so-called determinatives at the end of Egyptian and Babylonian words give to the practised eye a clue that is equivalent to the space which we moderns always leave between words; but to the casual inspector of the writing, the signs and symbols appear to run on in an unbroken sequence. There is nothing to indicate where one word ends and the other begins. Neither is there any variation in the type of letter to suggest the beginning of a sentence, or any mark of punctuation to indicate the end of a sentence or a shift in the phrase of thought. In short, the characters making up the text run on in an unbroken phalanx, from top to bottom of the page, and the better the manuscript is as a work of art, the more uniform and unvarying is the distribution of its characters. This applies, not merely to the oriental writings, but to the early Greek manuscripts as well. It is very puzzling, even to a person with a fair knowledge of the language, to attempt to decipher one of these continuous scripts. Doubtless the readers of the time, having, of course, a perfect familiarity with their language, found no difficulty in reading such a script. Yet the real embarrassments that hamper such a system will be evident to anyone who will have the most familiar sentence in his own language written on a typewriter with the omission of spaces between the words. Hereisaprintedsampleinillustration. The reader who stumbles a little over this sentence will be given a realizing sense of the difficulties that confronted a school-child of, for example, the Greek classical period.

It goes without saying that the shift from the unspaced, unpunctuated, unparagraphed sentence, to the modern method, was not made in a day or a generation. The study of a long series of manuscripts affords interesting illustrations of the slow invention of these conveniences and the unreadiness with which a conservative world adopted them. The old Persians were the only Orientals of antiquity who saw the desirability of indicating word divisions. Curiously enough, as it seems to us, they did not hit upon the plan of merely leaving a wider space at the end of words, but adopted, instead, the more laborious and less graphic method of placing an oblique line at a particular angle at the end of each word,—a line or, more accurately, a wedge-shaped mark differing in no respect, except in its angle of placement, from other marks that are variously grouped to make the characters of their writing.

It will be recalled that the Persians divide with the Phœnicians the honor of the invention of an alphabetical writing. In the light of this fact, it is interesting to recall that one of the oldest pieces of writing in the Phœnician alphabetical script, namely, the inscription of the Moabite Stone, shows a tendency to mark with dots the divisions between words. It appears, from this, that the idea of the separation of words had occurred to scribes of a very early day. Why so convenient an expedient, once suggested, should have failed of universal recognition, is food for conjecture. Whatever the explanation, it is a familiar fact that all the early Greek and Roman manuscripts are altogether guiltless of attempt at word separation, or of punctuation, and that tentatives toward the use of these convenient expedients did not begin to show themselves until we come to manuscripts of the old Roman period. Indeed, it is not until about the tenth century of our era that the manuscripts of Europe give evidence of the general adoption of word-spacing, punctuation, capitalization, and paragraphing.

As regards capitalization, indeed, the earlier writings afforded no opportunities, since the Greeks and Romans of the classical time and their successors of the early Middle Ages used capitals exclusively in writing their books. The development of small letters—the so-called minuscules—was a space-saving and time-saving invention of the monks of the seventh and eighth centuries. When the minuscule script had come into vogue, the capitals were retained at the beginnings of sentences, perhaps quite as much for their ornamental effect as for any other reason. And the same motive, perhaps, was instrumental in establishing the custom of paragraphing, but the need of word divisions and punctuation marks had made itself felt by scribes and readers who dealt with a language not their mother tongue, and these various accessories came in time to be regarded as absolute essentials.

The full elaboration of the system of punctuation marks now in vogue, was, however, a work of even more recent centuries. No manuscript, prior to the day of the printing-press, is punctuated in quite the modern fashion; but, for that matter, the popular method of punctuating varies a good deal from generation to generation. Just at present, for example, the colon is very much less in evidence on the printed page than it was fifty years ago.

But these are mere details. From a broader view it may be said that all of the modern aids to the reader had gained practically universal acceptance among the makers of books before the close of the Middle Ages. We have already seen that the books themselves at this period were almost exact prototypes of modern books as regards form and binding. Indeed, as already mentioned, the early printers made an effort to duplicate the written book, and it may be added that it is sometimes difficult to tell, at first glance, whether a book of the fifteenth century is a specimen of early printing, or a very perfect example of the writing of a scribe. It does no harm to recall that the connoisseur of the period regarded the printed book precisely in the same light in which a modern connoisseur of painting regards a chromo—as a cheap, meritricious, inartistic imitation, not to be countenanced by a person of taste or culture.

VII

THE PRINTING AND MAKING OF MODERN BOOKS

THE discovery of the art of printing is only one of the score of important things whose discovery must be credited to the inhabitants of the Flowery Kingdom. Judged by the standard of time alone, these Orientals have the advantage of Western nations by at least a thousand years, and for even a longer period for aught we know to the contrary. And yet, curiously enough, the Chinese language, in which the printed words are formed by symbols instead of letters, is probably less adapted to the use of movable types for printing than almost any other.

In point of fact it is not quite certain that the Celestials were familiar with the use of movable types, but there is no doubt that for many centuries before the discovery of printing in the West, it was customary in China to take impressions on paper from engraved surfaces. Certain books were engraved on slabs of wood and these slabs displayed in front of the universities for the benefit of the students. The students either took the impressions of these slabs themselves, or had them taken for them, thus collecting pages of an actually printed book. Several paper prints made in this manner in the middle of the third century are said to be still in existence.

The method of making these printed blocks was most simple. The scribe wrote with ink upon thin, transparent paper, which was pasted face downwards upon the wooden surface to be engraved. The engraver then cut out all the spaces between the black marks, leaving the type surface of the manuscript, from which impressions could be taken. It is quite possible that some form of movable types also was used for purposes of printing at this time; but, as suggested a moment ago, the Chinese method of writing by symbols instead of by the use of an alphabet does not lend itself to the use of movable types as do the Western languages. And even to-day a great deal of the printing in China is done from engraved blocks not unlike the slabs used by the university students two thousand years ago.

THE INVENTION OF PRINTING IN THE WEST

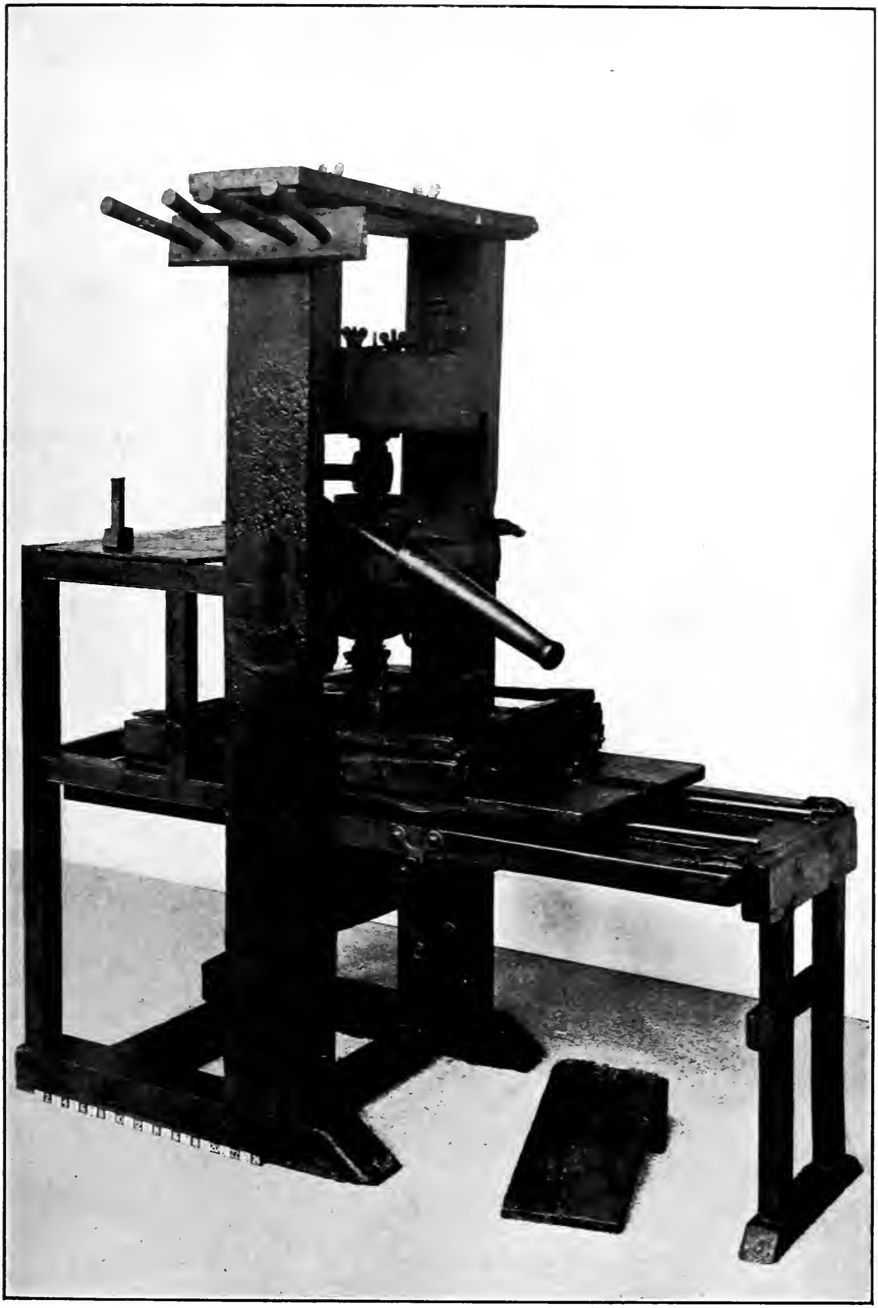
It is not an easy matter to determine who was the first person in the European world to conceive the idea of printing from movable types. There are several claimants, most of them from among the people in the north of Europe; but it seems all but certain that the first book actually printed from movable types came from the shop of Johannes Gutenberg, of Mainz, Germany, about the year 1450. He is generally regarded, therefore, as the "father of printing"; and despite the claims made on behalf of others, Gutenberg is likely to retain his place in history as the first printer.

The book he printed was very appropriately the Bible; and his press was about the simplest, as well as the first, ever invented. It consisted of two upright timbers, stayed at the top and bottom with two cross-pieces. There were also two intermediate cross-pieces, the lower of which supported the flat "bed" upon which the types were placed, the upper being pierced by the screw which was attached to the "platen," or flat surface which is pressed down upon the type. In using this press the type was clamped into a frame called a "coffin," on the bed. It was then inked with a leather ball stuffed with wool, the paper laid on carefully, a piece of blanket placed over this to remove inequalities, and the platen screwed down hard by means of a hand lever working on the screw. Between each impression the platen was raised by reversing the motion of the lever, and the blanket and paper removed.

This was a tedious process, and this kind of press about the simplest imaginable; yet it was neither changed nor improved upon for something over a hundred years, and it is responsible for the great flood of literature that spread over the Western world with such revolutionary effects during the fifteenth and sixteenth centuries. And while there is little resemblance between the great perfecting presses used in the large printing establishments to-day, and Gutenberg's little machine, there is no difference in the general principles of each. Indeed, the hand-presses now in use, and upon which the very finest cuts are made, are very like the first Gutenberg press, except that iron frames and metal parts have replaced those formerly made of wood.

The process of development was a slow one, even after the first departure from the earliest type of press was made. The first improvement was made by William Blaew, of Amsterdam, who improved the movement of the platen and simplified the work of manipulating the screw by a device for rolling in and out the bed, so that the platen need only be raised a short distance between impressions. This press soon became very popular all over Europe, and remained practically unchanged from its invention, in 1620, until the closing years of the eighteenth century. By that time the demand for more pressure upon the "form" caused the Earl of Stanhope to produce a press having a frame made of one piece of cast iron. He made several improvements in the system of levers for working the platen, which were also very advantageous to the pressmen. But his press was still only a modified Gutenberg press, as were those of Clymer, Rust, and Smith a little later; and the "Washington" press, which is even now the popular hand-press for taking fine proofs, is really only the perfected product based on all these models.

By the end of the first quarter of the nineteenth century many improvements had been made in presses, particularly in the manner of applying power, the old hand-presses having practically disappeared except for the special work just referred to. The press invented by Isaac Adams, of Boston, in 1830 and in 1836 was a very popular one; and Hoe & Company, of New York, were busy in the preparation of presses that should meet the increasing demands of the newspapers for faster work. But as yet few of these presses departed very radically from the original idea of a flat platen pressing



AN EARLY TYPE OF PRINTING-PRESS

This Caxton printing-press, now in the Victoria and Albert Museum, London, is known to be two hundred years old, and is still in good working order. This type of press is still used for printing fine engravings.

against a flat bed of type. The improvements had been largely in the mechanism for applying this pressure.

THE CYLINDER PRESS INVENTED

Early in the century an Englishman, William Nicholson, conceived the idea of a press which, instead of having a flat platen or a flat bed, should have one, or possibly both, of these in the form of a cylinder, so that the paper, instead of being laid upon the forms and pressed, should be fed between cylinders, just as any material is fed to a rolling-machine. But Nicholson, although he took out patents for his press, merely made drawings and plans without constructing a machine; so that his attempts, although perfectly practical as proved by later events, bore no fruit and he is not legitimately entitled to the credit of introducing the "cylinder press."

The practical solution of the problem must be credited to the Saxon, Friedrich Koenig. With the assistance of a London printer by the name of Bensley, he devised a cylinder machine in 1812–1813, and printed several books upon it. In this machine "the form of type was placed on a flat bed, the cylinder above it having a threefold motion, or stopping three times; the first third of the turn received the sheet upon one of the tympans and secured it by the brisket; the second gave the impression and allowed the sheet to be removed by hand, while the third returned the tympan empty to receive another sheet." This machine worked well, and was followed later bv several other machines by the same inventor, among them a cylinder machine that printed on both sides of the paper, and was called a "perfecting press."

At the same time that Koenig was working upon his presses several other inventors were producing machines on somewhat the same lines, most of these inventors being Europeans, America not having as yet entered the field with any serious competitor. Among these inventors was Napier, who produced a cylinder press which was equipped with grippers or "fingers" for the conveyance of the sheets around the cylinder during the impression, and for delivering them after printing. This was about 1830, and the advantages of this press were so obvious that two years later Robert Hoe, of New York, sent over to England a young man, Sereno Newton, to study the workings of these presses. The ultimate result of this fortunate event was the well-known firm of R. Hoe & Company, of which Newton was a member. That name is now associated with printing-presses the world over. Almost from the day that this company came into existence the centre of manufacture began shifting from the old world to the new; and to-day the American printing-press stands without a rival.

It should not be understood that the popularity of the American press was in the nature of a sudden mushroom growth. On the contrary the American manufacturers had struggled for half a century to compete successfully with their European rivals. But by the middle of the century they had overhauled them; by the end of the century they had completely outstripped them. A few

European presses occasionally make their way into this country from time to time, but the experiment is usually a costly one, as almost invariably they prove to be inferior to the home product.

It should not be understood that the cylinder type of press was unknown in America before Napier's invention. On the contrary the Hoe company had one on the market. But by combining European ideas with those already known, a cylinder press was soon produced, modified types of which are still in use, particularly in the book and pamphlet printing establishments. The development of the great rotary newspaper perfecting presses, that "do everything but talk," is another story that will be considered in a moment.

The cylinder press in use at the present time for the finest kind of letterpress work is really an American improvement upon a French invention. This is the "stop cylinder" invented by Dutartre in 1852, and introduced into this country a year later by Hoe & Company, who very shortly improved upon it, adding to these improvements year by year until the result is the marvelous machine of the present time. The stop-cylinder press has been recently described as follows:

"The type is secured upon a traveling iron bed, which moves back and forth upon friction rollers of steel, the bed being driven by a simple crank motion, stopping or starting it without noise or jar. All the running portions of this bed are made of fine steel as hard as it can be worked. The cylinder is stopped by a cam motion pending the backward travel of the bed, and during the interval of rest the sheet is fed down against the guides and the grippers close upon it before the cylinder starts, thus insuring the utmost accuracy of register. After the impression, the sheet is transferred to a skeleton cylinder, also containing grippers, which receives and delivers it over fine cords upon the sheet flyer, which in turn deposits it upon the table. The distribution of the ink is effected partly by a vibrating, polished, steel cylinder, and partly upon a flat table at the end of the traveling bed, the number of form-inking rollers varying from four to six. This is without doubt the most perfect flat-bed cylinder printing-machine that has ever been devised."[1]

But this type of cylinder press, while able to produce the best kind of work, is comparatively slow—too slow for the demands of the newspapers, which are forever crying for more speed. The best that the old-style cylinder press could do was only about two thousand impressions per hour, or about as fast as the feeder could lay the paper in place. This was of course altogether too slow, and a double-cylinder machine was tried, in which the bed was lengthened so that it was acted upon by two cylinders, and upon which two feeders worked. But even with this machine only four thousand sheets printed on one side could be produced per hour, and this was still far below the requirements.

THE ADVENT OF THE "TYPE-REVOLVING MACHINE"

It is a curious fact in the history of invention that great discoveries have frequently followed closely upon the announcement from authoritative sources that such discoveries would be impossible. Indeed this has occurred so frequently that some one was prompted to remark recently that one reason why the practical airship had not been invented sooner was because everybody expected that it would be. "Let all the scientists come to the agreement that aerial flight is impossible," said this cynic, "and very soon we shall fly."

Be this as it may, it is certain that the invention of a printing-press with the type revolving on cylinders followed closely upon the statement by the world's leading journal that such a machine was mechanically impossible. "No art of packing could make the type adhere to a cylinder revolving around a horizontal axis and thereby aggravating centrifugal impulse by the intrinsic weight of the metal," said the London *Times* in December, 1848. Ten years later the same paper was being printed by a machine of this impossible kind, the invention of the American, Richard M. Hoe.

It is perfectly obvious to anyone that there would be many advantages in a printing-machine to have the type arranged on the surface of a revolving cylinder which could be rotated continuously in one direction, printing a sheet at every revolution. But the difficulty, as *The Times* pointed out, lay in discovering some method of holding the type in place on such a machine. The imperative demands of the American newspapers, however, acting as a constant stimulus to inventors, caused them to make ceaseless efforts to produce such a machine, or one that would turn out more work; but it was not until 1846 that such a machine was perfected. In that year, a "Hoe Type-Revolving Machine" was placed in the office of the Philadelphia *Ledger* and soon demonstrated that a revolution in newspaper presses was at hand.

The actual output of this, and other similar machines, was limited to the number of sheets of paper that could be fed to it by hand—about two thousand sheets per hour—just as in the case of the flat type-bed machine where the paper is carried on a cylinder. But the great advantage lay in the fact that several paper-bearing cylinders could be acted upon at each revolution of the type-bearing cylinder, each one fed by an operator at the rate of two thousand sheets an hour. A single-cylinder machine could produce two thousand sheets; but the same cylinder revolving at the same speed could be made to increase its capacity two thousand sheets for every additional cylinder and feeder. As many as ten of these paper-carrying cylinders were grouped around type cylinders, the output of such a machine being twenty thousand papers an hour. By means of these "ten-cylinder rotary" presses the newspapers were, for the first time, able to meet the demands of their rapidly increasing circulations, and the day of the "ten-minute edition" was in sight.

Before these rotary machines had been perfected, however, another valuable discovery had been made. This was a method of casting stereotype plates on a curve. By this method it was possible to take duplicate impressions of the type, cast them as solid pieces of metal, and use them on the rotary presses just as the types themselves are used. In this manner a number of presses could be supplied with stereotypes made from a single setting of type, and requiring only the additional time of casting a plate for each machine. In some of the newspaper offices of New York and London as many as five of these machines were operated at the same time.

But still the capacity of these machines was limited to the possible speed of the hand feeders. The paper was fed in sheets cut to the proper size, and each one must be handled either by a human feeder or by some mechanical device. It was impossible to increase the speed of the printing cylinder, therefore, beyond the speed-capacity of the feeders. To overcome this defect several inventors began experiments with machines that would do away with feeders and single sheets of paper, printing from continuous rolls or "webs" of paper, and cutting off the paper into proper lengths after the impression had been made.

To those unfamiliar with the subject, this undertaking would seem to be a comparatively simple one, consisting essentially of some device for cutting off the paper at definite intervals; but in practice many difficulties were encountered. First of all there was difficulty with the inks, and ink-makers were urged to produce rapid-drying and "non-setting-off" inks; and these were soon produced. Another difficulty was in obtaining paper in the roll of uniform strength and perfection; but paper manufacturers, by giving special attention to the making of these rolls, soon produced a satisfactory product. But, curiously enough, the problem of rapidly severing the paper was one of the most perplexing to the inventors, and was not solved until 1871, in a new Hoe machine. In this the sheets were not entirely severed by the cutters, but simply perforated, and then drawn by accelerating tapes, which completely separated them, into a gathering cylinder so constructed that six perfect papers, or any other desired number, could be gathered one over the other. These were delivered to the receiving board by an ingenious device patented by Stephen D. Tucker, of the firm of Hoe & Company.

The many advantages of this new machine were so apparent that the earlier types of presses were quickly discarded by the great newspaper offices. A London paper, *Lloyd's Weekly Newspaper*, headed the list, and was followed shortly by the *Tribune* in New York; while other papers soon followed their example. There seemed to be no limit to the printing capacity of these new presses except the ability of the paper to stand the strain. As many as eighteen thousand perfected papers could be turned out in an hour, although the average was usually a few thousand less than this.

It was not until 1875, however, that a satisfactory folding device was perfected. Until that time the extreme limit of the folders in use was eight thousand papers an hour; but in that year Stephen D. Tucker again came forward with an invention, a rotating folding cylinder, that folded papers as fast as the presses could print them.

It would seem by this time as if the ingenuity of press inventors must be exhausted, and that the "perfecting" press was as nearly "perfected" as possible. But this was by no means the case. A paltry output of fifteen thousand carefully folded newspapers per hour for a press was far from satisfactory, and soon new presses were produced that trebled this capacity. Thus the press placed in the office of the New York *World*, in 1887, had a capacity of forty-eight thousand papers an hour, "all delivered with great exactness and perfection, cut at the top, pasted and folded ready for the carrier or the mails."

A MODERN NEWSPAPER PRESS

Four years later a new *Herald* press eclipsed even this monster. It required eighteen months for the construction of this press, which was composed of about sixteen thousand separate pieces. It was described in the *New York Herald* of May 10, 1891, in part as follows:

"The new Hoe press which is being set up in the *Herald* Building is nothing less than a miracle of mechanism. To say that it is the only one of its kind ever built and that it throws all previous inventions into the background are facts which the following figures abundantly prove.

"Its consumption of white paper is so astonishing that even the imagination grows tired and sits down to catch its breath. It is fed from three rolls, each being more than five feet wide. When it settles down to show its best work it will use up in one hour nearly twenty-six miles of this paper, or to make the matter more significant, it will use up about fifty-two miles of paper the ordinary width of the *Herald* every sixty minutes.

"Our readers will be startled to learn that it can print and fold ninety thousand four-page *Heralds* in an hour. This is, to the mind which is not versed in the problem of rapid printing, a feat which makes Aladdin's lamp an old woman's fable. Ninety thousand per hour means fifteen hundred copies per minute, or twenty-five copies for every second ticked off by the clock in Trinity's steeple.

"This press will print, cut, paste, fold, count, and deliver 72,000 eight-page *Heralds* in one hour, which is equivalent to 1200 a minute and twenty a second.

"It will print, cut, paste, fold, count, and deliver complete 36,000 sixteen-page *Heralds* in one hour, which is equivalent to 800 a minute and a fraction over thirteen a second.

"It will print, cut, paste, fold, count, and deliver complete 24,000 fourteen-, twenty-, or twenty-four-page *Heralds* an hour, which is at the rate of 400 a minute, or very nearly seven a second.

"This is lightning work with a vengeance, and yet it is possible that there may be some who read this who will live to call it slow. That will probably be when they have found all about how to put a harness on electricity. No one can predict when inventive genius will reach its limit in the printing-press. But for the present this new press marks high-water mark.

"The new press has a well-nigh insatiable appetite for white paper. To satisfy it, it is fed from three rolls at the same time, one roll being attached at either end of the press and the third suspended near the centre. Each roll is sixty-three inches wide, or twice the width of the *Herald*. When doing its best this press will consume

$25\frac{7}{8}$ miles of sixty-three-inch-wide paper—equivalent to $51\frac{3}{4}$ miles of paper the width of the *Herald*—in one hour and eject it at the two deliveries. It is a sight worth seeing to see it done. Certainly we know of nothing else which affords such a striking example of the triumph of mechanical genius.

"A man turns a lever, shafts and cylinders begin to revolve, the whirring noise settles into a steady roar, you see the three streams of white paper pouring into the machine from the three huge rolls, and you pass around to the other side—it is literally snowing newspapers at each of the two delivery outlets. So fast does one paper follow the other that you catch only a momentary glitter from the deft steel fingers that seize the papers and cast them out.

"The machine weighs about fifty-eight tons. It is massive and strong with the strength of a thousand giants. And yet though its arms are of steel and its motions are all as rapid as lightning, its touch is as tender as that of a woman when she carries her babe. How else does the machine avoid tearing the paper? It tears very readily, as you often ascertain accidentally when turning over the leaves. Truly wonderful it is, and mysterious to anybody but an expert, how this huge machine can make newspapers at the rate of twenty-five a second without rending the paper all to shreds.

"It has six plate-cylinders, each cylinder carrying eight stereotype plates which represent eight pages of the *Herald*, and six impression-cylinders These cylinders, when the press is working at full speed, make two hundred revolutions a minute. The period of contact between the paper and the plate-cylinders is therefore inconceivably brief, and how in that fractional space of time a perfect impression is made, even to the reproduction of such fine lines as are shown in the illustrations, is one of those things which, to the man who is not 'up' in mechanics, must forever remain a mystery. But that it does it you know, because you have the evidence of your own eyes.

"A double folder forms part of this machine. A single folder would not be equal to the task imposed upon it. As it is, this double folder has to exercise such celerity to keep up with the streams of printed paper that descend upon it that its operations are too quick for the eye to follow.

"The press has two delivery outlets. At each the papers are automatically counted in piles of fifty. No matter how rapidly the papers come out, there is never a mistake in the count. It is as sure as fate. By an ingenious contrivance—if I should attempt to describe it more definitely most people would be none the wiser—each fiftieth paper is shoved out an inch beyond the others that have been dropped onto the receiving tapes, thus serving as a sort of tally mark.

"Truly it is a marvelous machine—this sextuple press. Nowhere will you find a more perfect adaptation of means to ends; nowhere in any branch of industry a piece of mechanism which offers a finer example of what human skill and ingenuity is capable of."

From this it will be seen that at least one desideratum of the printing-press, speed, had been attained. But there was still much to be desired in the way of quality of work. A hundred thousand folded and pasted newspapers could not be turned out by a single machine every hour without great sacrifice in quality of the presswork. And yet the quality was marvelously good, all things considered. So good, indeed, as to warrant the belief that it was simply a question of perfecting the details of the existing rotary presses to make them produce letterpress of "magazine" quality. In fact, while the great press just described was under construction, the same builders were planning another marvel, which should do for the magazines what had been done for the newspaper. How well they succeeded is attested by the fact that the new press was requisitioned for doing the plain forms of one of the best printed periodicals in the world, by the master-printer, Theodore L. De Vinne, whose reputation as a printer rests upon the excellent quality of his work.

A PERFECTED MAGAZINE PRESS

In an article contributed to the *Century Magazine* Mr. De Vinne described this new press as follows:—

"At the end of a long row of machinery," he says, "stands the web press—a massive and complicated construction, especially built by Hoe & Company, for printing, cutting, and folding the plain and advertising pages of the *Century*. Web presses for newspapers are common enough, but this press has the distinction as the first, for good book-work. At one end of the machine is a great roll of paper more than two miles long when unwound, and weighing about 750 pounds. As the paper unwinds it passes first over a jet of steam which slightly dampens and softens its hard surface and fits it for receiving impressions, without leaving it wet or sodden. It passes under a plate-cylinder, on which are thirty-two curved plates, inked by seven large rollers, which print thirty-two pages on one side. Then it passes around a reversing cylinder which presents the other side of the paper to another plate-cylinder, on which are thirty-two plates which print exactly on the back the proper pages for the thirty-two previously printed. This is done quickly—in less than two seconds—but with exactness. To do this it is drawn upward under a small cylinder containing a concealed knife, which cuts the printed web in strips two leaves wide and four leaves long. As soon as cut the sheets are thrown forward on endless belts of tape. An ingenious but undetectable mechanism gives to every alternate sheet a quicker movement, so that it falls exactly over its predecessor, making two lapped strips of paper. Busy little adjusters now come into play, placing these lapped sheets of paper accurately up to a head- and a side-guide. Without an instant of delay down comes a strong creasing blade over the long center of the sheet and pushes it out of sight. Pulleys at once seize the creased sheet and press it flat, in which shape it is hurried forward to meet three circular knives on one shaft, which cut it across in four equal pieces. Disappearing for an instant from view, it comes out on the other side of the upper end of the tail of the press in the form of four folded sections of eight pages each. Immediately after, at the lower end of the tail of the press, out come four entirely different sections of eight pages each. This duplicate delivery shows the product of the press to be at every revolution of the cylinder sixty-four pages, neatly printed, truly cut, and accurately registered and folded, ready for the binder.

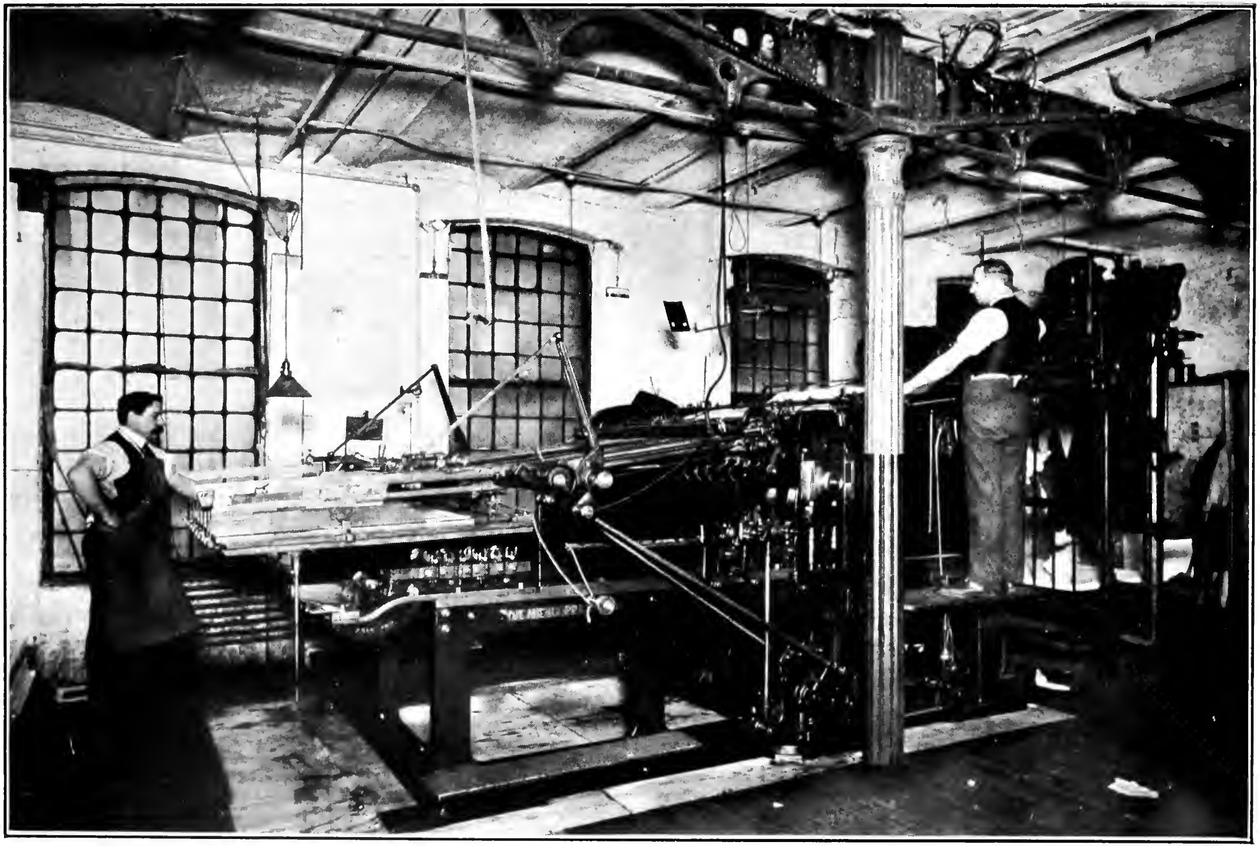
"Two boys are kept fully employed in seizing the folded sections and putting them in box trucks, in which they are rolled out to the elevator, and on these sent to the bindery. This web press is not so fast as the web press of daily newspapers, but it performs more operations and does more accurate work. It is not a large machine, nor is it noisy, nor does it seem to be moving fast, but the paper goes through the cylinders at the rate of nearly two hundred feet a minute. It does ten times as much work as the noisier and more bustling presses by its side."

The fact that so exacting a master-printer as De Vinne was satisfied with the work of the new rotary press stimulated the press manufacturers to produce a rotary press that could be used, not only for the plain parts of magazines, but for woodcut and half-tone illustration printing. As a result the "Rotary Art" press was put into operation within a few months after the press just described, turning out as good work of all kinds as can be done by stop cylinder, or hand-press.

But even this triumph does not close the chapter of progress in printing. In one-color printing, to be sure, there is little left to be done, for speed and quality of the presswork are verging on what we may be allowed to call perfection, judged by modern standards. But there is still the enormous field of color printing, that is now only in its infancy. "The demand for printed matter seems to increase with the ability to furnish it," says a recent writer, "and much attention is now being directed to the subject of color printing on the rotary system. From present appearances and from the enterprise displayed by the publisher, the artist, and the press-maker, it would seem as though the day is not far distant when this subject alone would furnish matter for a new chapter in the history of the printing-press."

And, indeed, for anything but the very finest kind of color printing, the matter for this chapter is already in hand. In a later chapter in this volume this subject will be again taken up in detail with particular reference to the scientific aspects of the color combinations; but, as will be seen there, the matter of perfection is really "up to" the presses, and they are making strides that are certain shortly to close the gap.

"The last three or four years have witnessed an immense advance in the art of color printing. The magazine without an elaborate color cover, or perhaps colored illustrations, is now an exception, whereas it was the reverse not long ago. After satisfactory experiments it was ascertained that, with the inks properly prepared, and suitable plates to print from, colors could be printed almost simultaneously upon the paper, without mingling; in short, that the supposed necessity, in much of the work done, of drying the sheets after the impression of each color on the paper, was not necessary for the production of a good quality of printing. Further experiments also proved the mechanical possibility



A VIEW IN THE PRESS-ROOM OF HARPER & BROS., NEW YORK CITY

A modern book and magazine printing-press in operation.

of obtaining most accurate register in printing from the roll, and that the number of impressions, or colors, could be increased to advantage." At the present time these great rotary color-printing machines have been brought to a stage of perfection so that from ten to twelve colors are now printed at a single journey through the press, at the rate of about 100,000 copies an hour.

OTHER AIDS TO THE PRINTER

It should not be understood that it was simply in the matter of presses that the publishing world made giant strides of progress in the latter half of the nineteenth century. Indeed, had there not been a correspondingly rapid development in other fields, the great rotary presses would have been of little account. For such presses must be fed, not only with paper and ink, but with ever changing type, which, if set by the slow hand-method, piece by piece, would not keep the greedy rotary monsters supplied. But fortunately the invention of devices for setting type rapidly was keeping pace with the capacity of the presses to use them.

As everyone knows, the old method of setting type—the only one known until two decades ago—was that of picking out each individual type by hand, and placing it in a certain position on a special device for holding it, called a "stick." The limit of speed of type-setting, therefore, was governed by the capacity of the individual type-setter, or the number of men employed. There was no means of hastening the process except by increasing the number of men. But with the improvements in the presses, and the demand for constantly changing "copy" in the different editions of the daily papers, the hand-setting methods were found to be a constant drag. It was not until early in the '80s, however, that any mechanical aids were devised. But since that time type-setting and composing machines have almost completely supplanted hand-setting methods.

The different kinds of machines that have taken the place of hand setting all fall into one of three general classes. There are those in which ordinary types are used, but in which the setting is done by the aid of a keyboard working in much the same manner as the ordinary typewriter keyboard, the pressure of each key setting in motion machinery that places the corresponding type in its place on the stick. There are also machines in which no type is used, the letters being formed on a bar by the manipulation of a keyboard, and cast in slugs of one line each, so that the operator literally casts his type as he goes along. And there is still a third class, quite as wonderful, with which the operator uses a machine provided with a keyboard, the letters of which, when depressed, punch holes in a roll of paper. This roll is then placed in a steam-driven machine which interprets the holes in the strip of paper into type corresponding to the keys depressed by the operator, casting them one by one at the rate of something like a hundred a minute, and placing them in position ready for the presses.

Each of these classes of machines has its advantages and disadvantages, which may be considered for a moment before examining the individual machines in detail. The type-setting machines proper, in which ordinary types are used, labor under the disadvantage that they have to be "loaded" with type before they can be operated; and until recently these types had to be re-distributed after the printing was done. But the importance of this defect has now been lessened by the invention of marvelous type-casting machines, which cast over a thousand types a minute, placing them in such position that they can be loaded into the type-setting machine ready for action in a few seconds. This can be done so cheaply that it no longer pays to distribute the type after it is set, a new dress of type being used every time printing is done. This kind of type-setting and type-casting machines is in use in some of the largest printing offices in the world, particularly in Europe.

The machines that make their types, or slugs that correspond to types except that they are in one-line lengths instead of single types, are those known as "linotype" machines. These have so many advantages over ordinary single type-setting machines that they are very properly the most popular machines for certain kinds of work; particularly where speed rather than accuracy is the desideratum. The disadvantage of these slug-machines is that if a mistake is made anywhere in one of the lines, the entire line must be made over again, instead of being corrected in the ordinary manner. For this reason, where there are likely to be a great number of corrections, as in the case of authors' manuscripts, the final cost of composition with linotype machines may be greater even than handwork. Where there is no necessity for numerous corrections, however, the linotype setting is probably the best, and the cheapest, of any of the mechanical type-setting processes.

The kind of machine that makes its own types automatically and individually from holes punched in strips of paper, such as the Lanston monotype machine, has practically all the good features, and very few of the bad ones, of the other two. It is a relatively delicate mechanism, however, and for this reason much more liable to get out of order than either of the other machines. Nevertheless, the monotype machines have practically superseded all others for the fine class of work formerly done by hand.

Both the linotype and monotype machines are such marvels of ingenuity that they are worth considering somewhat in detail. As they have been described recently by an eminent authority on the subject, I take the liberty of quoting him in part here.

THE MERGENTHALER LINOTYPE

"The linotype machine, invented by Ottmar Mergenthaler, of Baltimore, Maryland, became commercially successful during the early '90s. The machine is less than five feet square, and weighs about two thousand pounds. It consists of a bank of keys connected with a magazine containing about fifteen hundred brass matrices—small plates about an inch wide—the thickness varying with the type character. On one edge is the die from which is cast the letter, and at the upper end are a series of nicks or teeth for distributing purposes, and every character possesses a different combination. Each magazine contains a number of matrices for each letter, and all the usual characters required by a complete font of type, together with spaces, quads, etc., of varying thicknesses. In addition there are also flat, elongated, wedge-shaped spaces which are inserted between words and employed for justifying each line as it is cast.

"The magazine containing the matrices is an inclined receptacle two feet six inches high, the top being about six feet from the floor. Within this magazine are channels in which the matrices for the different letters are stored, and through which they pass. The machine is so adjusted that as the keyboard is manipulated the matrices are selected in the order in which they are to appear in the slug or casting. When a key is depressed, the matrix to which it corresponds emerges from its channel, is caught upon an inclined traveling belt, and is then carried to the assembler, or stick. As each word is completed, a stroke of the space-key inserts the wedge-shaped space used between each two words. When the line is completed the operator can correct errors by extracting matrices or substituting other for those which are in the line. The wedge-shaped spaces are now pushed up through the line, securing instantaneous and complete justification. The completed line is then transferred automatically to the front of a mold extending through a mold wheel at the left. Behind the mold is a melting-pot, heated by gas or gasoline, and containing molten metal. Within the pot is a pump-plunger leading to a perforated mouth arranged to close the rear of the mold. When the matrix line is in position the automatic operation of the plunger forces the metal into the mold and against the line of matrix letters, where it instantly solidifies in the form of a slug. The mold wheel then makes a partial revolution, bringing the mold in front of a blade which pushes the slug into a receiving galley, ready for the proof press.

"Having served their purpose in front of the mold, the matrices are returned to the magazine to be utilized in new combinations. The distribution is accomplished automatically. The operation of the machine permits the composition of one line, the casting of a second, and the distribution of a third to be carried on simultaneously. The casting operation can also be arranged to work independently of the rest of the machine. It is said that this machine is capable of a speed greater than that at which the most skilful expert can operate the keys. The average product of a good operator is 4000 ems per hour. Many operators, however, can produce from 5000 to 6000 per hour, and a speed of 13,000 is on record."

There is another machine, known as the "monoline," that is operated in much the same way as the linotype. In this machine "as the keys are struck on the keyboard the matrices and spacers descend into the assembling box, traveling a distance of about four inches, and the bars are dropped more or less, according to the position of the letter to be brought in line to be cast. When the line has been completed to approximately its full length, the operator strikes a lever at the right of the keyboard, and begins the composition of the second line, while at the same time the machine automatically justifies the first line, carries it to the casting-pot, delivers it upon the galley, and returns the matrices and spacers to their respective receptacles in the magazine. The machine will not cast a line that has not been properly justified"—that is, the lines made even in every way.

THE LANSTON MONOTYPE MACHINE

"The Lanston monotype machine was invented by Tolbert Lanston, in 1886, but was not placed on the market until more than ten years later. The principle upon which it is constructed differs radically from that of the linotype. The monotype produces single types cast in the order of their use, and set in automatically justified lines. It consists of two machines—a perforating device operated by a keyboard, and a casting machine. The keyboard differs from that of a typewriter only in the much greater number of characters, of which there are two hundred and twenty-five, comprising a complete font, including italics and small capitals. The keys are arranged in fifteen columns of fifteen rows each, with two extra rows at the top to secure justification. For each series of characters in the font a different color is used, so as to distinguish italic from roman fonts, etc. The keyboard is between three and four feet from the floor and is supported by an iron bar upon a base one foot square. At the top of the machine is a roll of paper which unwinds from one spool and winds on another as the keys are struck, and also a paper scale for registering the body-size of the type.

"Before beginning his task, the keyboard operator sets an index of the number of ems required per line. Each stroke of a key perforates the paper ribbon in such a combination as to control the matrix of the proper letter in the casting machine, and causes the registering scale to charge to the line an amount equal to the body-width of the type just selected. In this way a line of matter is progressively perforated and charged until, as the end is approached, the line-scale shows that the next word or syllable cannot go into that line, while another portion of the registering scale indicates the amount of unfilled space in the line just perforated if it should be cast with its spaces of normal body size. Still another portion of the scale has been keeping account of the number of spaces used between words of the line, which may be varied in the process of justification. The machine thus mechanically notes for the operator the amount of space to be added, and the number of space-types among which the variation from the normal body-width may be apportioned. At the completion of each line the operator, by merely noticing the figures shown by the pointer on the justifying scale, knows at once what additional holes to perforate in the record in order to secure perfect justification. When he has touched the justifying keys the registering scale points to zero, advancing again as the new line progresses. These operators are all automatic.

"From the perforator the spool passes to the casting and setting machine—an intricate piece of mechanism about four feet high and slightly less in width, weighing about twelve hundred pounds. On being placed in the casting machine the ribbon is unwound in reverse order, the operation of casting and setting proceeding in like manner. The control of the casting machine by the perforations in the ribbon is effected by the pressure of air passing through the holes as the ribbon moves over a rounded plate. Within this plate are thirty-two air-tubes, and, as different perforations appear, different connections are made through these tubes with the working parts of the casting machine, a pressure of eight pounds being maintained. The two hundred and twenty-five matrices are contained in a die case measuring about three inches square. The matrix case shifts its position according to the kind or combination of perforations passing over the air-tubes. The perforations for justification regulate the casting of space-types between words, causing the mold to be opened in a degree indicated by the justifying holes, in order that the space-types may be cast of the proper size. Thus from the record ribbon made at the keyboard, the casting machines cast type and insert mathematically correct spaces at constant speed which may be kept up to the limit of cooling metal. It is the work of only a few moments to remove one matrix case and substitute another. Moreover, the molds in which the bodies of the types are cast, also may be exchanged at short notice.

"At one side of the casting machine is a melting-pot, in which an automatic plunger forces the hot metal into a nozzle leading directly to the mold upon which the matrix rests. The metal is forced against the matrix, which is filled first, and then instantly occupies the body of the mold under pressure, insuring a good cast. When chilled, the types are ejected through the mold into the carrier, which carries them to the line in the galley. As each line is completed, it is advanced automatically to make room for the next. The correction of matter set on the Lanston machine is the same as in hand composition; it is not necessary to recast a line, as in the slug machines.

"It should be observed that the keyboard and casting machine have no connection whatever, and that each part can be operated independently. A keyboard operator can set matter as rapidly as he can read the copy and strike the keys, a speed of 5000 ems per hour being regarded as a moderate average. The type-casting machine casts and produces, according to the body size, from 75 to 125 ems per minute, or from 4000 to 5000 per hour."

From this it will be seen that this machine is a marvel of ingenuity. Yet, despite its complexity, it is entirely practical, and is undoubtedly the favorite composing machine at the present time. It may interest the reader to know that the pages of the present volume were composed on Lanston machines. The beauty and clearness of type and the evenness of justification speak for themselves.

THE GRAPHOTYPE

The Lanston has a rival, however, that has recently been placed upon the market, which is so simple, and has so many features in common with the ordinary typewriter, that it is peculiarly attractive. This machine is known as the "graphotype" and differs from the other machines just described in that it is run by electricity.

It is the invention of J. H. Goodson, who placed it upon the market in 1899. "It is composed of two parts; a small table about the size of a typewriter desk, containing an ordinary typewriter, a perforating machine, and a small dial similar to a clock; and a caster and setter. The typewriter is in all respects unaffected as far as facility in writing is concerned. The operator is required, in addition to the execution of ordinary typewriting, to notice, when the end of the line is reached, the dial which controls the spacing, and to touch the key indicated by the dial, thus automatically spacing and justifying the line.

"Each time a key is touched, not only is the proper letter written, but an electrical communication is made with the perforator, which perforates a narrow paper ribbon in a series of round holes so arranged that when the ribbon is placed in the casting and setting machine, a similar electrical connection is made through this perforation, by indicating the letter or space to be cast and set. The advantage of a visible, typewritten sheet is obvious. It is accessible to the operator for reference, and it may be read by the proof-reader instead of the first proof, as the type and the typewritten page are identical so far as the orthography is concerned. The ribbon, together with the corrected typewritten sheets, may be put away indefinitely for reprint or for possible use in the future, without expense for retaining metal."[2]

TYPE-SETTING MACHINES

It would seem that there would be little call for type-setting machines proper—that is, machines that actually set the types themselves instead of making them as they go along—once the monotype and linotype machines were invented; and in America such machines are not popular. But in Europe they are preferred by some of the largest and most progressive printing houses. The fact that type-casting machines have been brought to such a high stage of perfection, and that the types can be filled into the magazines of the type-setting machines automatically, has made it possible for these machines to compete at all. Yet there is unquestionably one decided advantage in this kind of machine: the operator has the composing stick, with the type falling into place, directly in view, so that he can read and correct mistakes as he goes along. In this way he is able to turn over to the pressmen more nearly perfect copy than is possible with either of the other machines.

Despite these slight advantages of the type-setting machines, however, it is probably right to regard them as obsolescent—as the highest representatives of a mechanical system that has been superseded by an entirely different and better one. Electricity is certain to come more and more into use as in the case of the "graphotype," just described, and with the simplifying of mechanisms that is sure to follow, machines that make and set their type at the same time are sure to gain in popularity. Nevertheless it would be unjust to the type-setting machines, which are marvels of ingenuity, to pass them on without a more detailed description of one of the well-known makes. There are several which work perfectly and apparently with equal efficiency, but the Dow machine may be taken as a representative type.

This machine consists of two parts, a composing machine for setting the type, and a distributing machine, the mechanism and operation of which have been described as follows: "The composing machine is a little over six feet high, and weighs about two thousand pounds. It is operated by means of a keyboard similar to that of a typewriter, but with ninety characters. The keys descend only three thirty-seconds of an inch, and are used simply to release certain parts, the driving power of the machine accomplishing the rest of the work. For greater ease in handling, the main type-magazine is divided into two parts. In the type channels, which are four feet in length, the types lie with their faces in sight, resting on their sides in order that a large number may be placed in one channel. For further increase of capacity, additional channels are devoted to letters in frequent use.

"At each touch of the keyboard a single type is pushed from the magazine and advanced to a type raceway in front of, and parallel with, the magazine. This raceway, which is in a continuous horizontal line, widens at one end, so that as the type enters and is pushed along by a rapidly reciprocating type-driver, it is stopped at the center by the narrowing of the race-way. From this it is conveyed into an upright channel or "stick," each type forcing down the preceding one.

As the types enter the stick their faces are presented directly in view of the operator, who can read and correct them at will. A bell gives warning when a line is approaching completion, and a gage at the side of the channel in which the line of type is formed, shows how much the line is short or how far the operator has overrun the standard measure he is setting. When the line is full the operator touches the line key, and then without further attention on his part, and without delaying the composition of the next succeeding line, the stick of type turns half-way round and the line of characters is thrust by a blade to a point on the raceway called the "bridge," where the process of justification begins.

"The Dow distributor is entirely separate from the composing machine, but its mechanism is of the same positive character. The operation by which it distributes the various types in their respective channels is automatic, and allows a normal speed sufficient to supply three composing machines with type. For purposes of distribution the body of each type-character has a special identifying nick. The distributor, which lies flat, consists of a central disk joined to a set of channels radiating like a fan. Upon the periphery of the disk are supported thirty-six type-carriers, and as these are rotated past the galley channel on one side, each receives a single type, which is carried round until it is opposite the proper channel, when it is pushed out of the carrier into the channel, the distributor continuing its rotation."[7]

BOOKBINDING

No better example of how necessity has stimulated invention is known than that of the development of bookbinding. When the only method of making books was the tedious process of writing them, the bookbinding methods were correspondingly deliberate. When printing was introduced, bookbinders discovered new materials and methods, and were soon able to keep pace with the production of printed sheets. And when the great advance in the methods of mechanically setting type and reproducing pictures was made a quarter of a century ago, which for the moment seemed to threaten to flood the market with more printed material than the bookbinders could handle, the binders responded with inventions of automatic machinery that could put covers on books as fast as the printers could supply them.

It is an interesting thing that, while the changes in making book-covers and in bookbinding have undergone so many revolutions, the shape of the finished volume has remained practically unchanged for a thousand years. The books of the ninth century which are still preserved are practically the same shape as those made to-day. The scroll, folded book, fan-leaved book, and probably a number of other forms had all been tried in preceding centuries; but the ideal form—leaves bound between two covers and free upon three edges—was attained, as we have seen, over a thousand years ago, and has never been improved upon.

In point of luxuriousness the modern book-cover is sadly degenerate. Covers are still made of costly material—silks and fine leather, and gold, and "pearl" trimmings—but the covers with clusters of precious gems, with gold hinges, clasps, and locks, and delicately carved ivory, have passed away with the other relics of the Dark Age. And yet the cover of the modern book, as in the case of the medieval tome, is usually the most costly part of the volume. The relative values have probably changed very little, for the manuscript volume was expensive.

In medieval times, and indeed until well into the eighteenth century, wood was the favorite material for the sides of book-covers. Some of these covers of the early period, with "their metal hinges, bosses, guards, and clasps, seem, in all but dimensions, fit for church doors." But as soon as the printing-press came upon the scene this heavy type of cover was replaced by lighter and less clumsy ones. At first these were still made of thin boards, covered with leather or cloth; but as the art of manufacturing paper became better understood, this substance gradually replaced all others.

For several centuries after the invention of the printing-press the whole process of bookbinding was done by hand. The sheets were folded by hand as they came from the presses, sorted, and sewed together by hand. The covers were made practically without the aid of any machinery, so that frequently the reputation of a bookbinder rested entirely upon his individual manual dexterity. Artistic taste also entered into the estimate, and upon a combination of these qualities rests the fame of the early binders such as Grolier, Le Gascon, Pasdeloup, Derôme, and, later, the Englishman Roger

Payne. And it is only within the last generation that machinery has completely supplanted the older hand-methods. Indeed, the giant strides toward mechanical perfection and automatic action in bookbinding machinery were not made until the very end of the last century.

In many ways, perhaps the most interesting period in the history of bookbinding was just before the close of the nineteenth century, when machinery was used for many of the different processes but while there was still a large amount of handwork done in the final process of binding. The method of that time, before the automatic machines robbed the art of every semblance of romanticism, was briefly as follows:

The printed sheets were folded together and made up into volumes which were compressed by passing through rollers placed a certain distance apart. "The volumes are then adjusted and clamped up in the laying- or cutting-press for the operation of *sawing the back.* Two or three grooves are, in this operation, sawn straight across the back of the volume, according to the number of bands on which the book is to be sewed. Into these grooves the bands are lodged, so that when the sewing of the book is complete, the bands are flush with the rest of the back, instead of projecting out as they did in olden times. A slight cut is made near each end for holding the 'kettle stitch,' or stitch by which the sewer fastens her thread each time she passes up and down.

"The *sewing* is done at an apparatus called the sewing-press or frame, upon which the number of cords to be employed are fastened at proper distances, in accordance with the saw-marks in the back of the volume. The method of sewing varies according as the sewer is working one or two 'sheets on,' and the number of bands employed may be from two to six, according to the size of the sheet, weight of the book, etc. When taken out of the sewing-frame the fly leaves are pasted on, and, the volume being neatly squared, the back is covered with a coating of thin glue; it is then laid on a board and allowed gradually to dry. When the glue is quite dry the back is *rounded* by beating with a hammer, and subsequently the volume is placed between two feather-edged boards, above which the back projects slightly. These are then placed together in a lying-press, for the *backing* process, that is, the back of the book is well beaten until it projects a little over each side of the beveled board, so as to form a groove or place for the millboard covers to lie in.

"The book is now ready for *boarding*. The boards were formerly, as the name indicates, really of wood, but now of millboards of various thicknesses, according to the size of the book. They are cut a little larger than the book itself, and are attached by the ends of the bands, left for that purpose, being passed through holes in the sides of the boards. The ends of the slips or bands are then frayed out, pasted down, and hammered flat and smooth.

"The volume is next placed between pressing-boards, and put with others into the standing-press, where it is submitted to a powerful pressure for several hours. Thereafter it is again fastened into a lying-press for cutting or *plowing* the edges with a knife-edged instrument called the plow. The object of the binder in this operation is to make every page of uniform size, presenting a smooth and equal 'head,' 'tail,' and 'fore-edge.' The binder is careful to leave as broad a margin as practicable; but the size of the smallest sheet is the real gage of the whole book. The head is first cut, next the tail, and before the face is cut it is necessary to have the back flattened by passing 'tringles' through between the cords and the boards. After the face has been plowed the back springs back into its rounded form, and thus the face presents the appearance of having been cut in the round."

This is the way in which most of the books on the market were bound until about 1890. Then improvements and inventions of bookbinding machinery began crowding out the slower hand-processes, just as the new type-setting machines and improved presses were crowding out the older methods in the printer's domain, until it is almost literally true that as books are bound at present in the large binderies, "the binder throws in the material and the machines do the rest." Hand-stitching is obsolete, the modern stitching-machines in use being able to stitch books or pamphlets, of almost any thickness, either with cord or wire, as the binder may desire. Instead of a number of hand operators for performing the various tasks in the preparation of magazines—for example, gathering, collating, selecting covers, and stitching—as of old, a single machine now takes the sheets from the feeders, folds, gathers, collates, covers, and wire-stitches copies of magazines and pamphlets, delivering them ready for distribution.

A steam rounding and backing machine has come into use which increases the capacity of the binder tenfold. Binderies with a former capacity of five hundred volumes a day now produce five or six thousand by using machines of this type. The new cover-making machine feeds itself from a roll of cloth which it cuts into pieces of the proper size as it goes along. It pastes these on the boards, fastens edges, smooths backs and sides, and drops the finished cover into a receptacle automatically, doing in seconds what formerly took several minutes to perform. Another interesting machine covers paper books and magazines at the rate of over twenty thousand a day.

Of course leather-covered books cannot be bound by machinery in the same manner as cloth-covered ones; but even the processes involved in leather bindings are now mostly done by machinery. And it is almost certain that within a short time leather books as well as all other kinds will be bound automatically by machinery, with a corresponding cheapening of prices, since, as has been pointed out, the binding is the most expensive part of book manufacture.

VIII

THE MANUFACTURE OF PAPER

DESPITE the revolutionary changes that have taken place in paper manufacture in recent years, whereby great steam-propelled machines produce all but the very finest grades of paper at an enormous rate, it still remains true that Western makers are unable to equal those of the Orient in the production of certain papers. The finest papers of China and Japan cannot be duplicated by Western manufacturers. "Why should they equal us?" asks the Celestial paper-maker, "since they are so new to the business. They have known the art for only a scant millennium, while we have been making paper for more than twice that length of time."

It is probable that surrounding conditions, rather than the matter of longer experience, account for this advantage of the Oriental paper-makers, although there is no denying them the claim that the art was old in the East before the West became familiar with it. Indeed, the West had never heard of such a substance as paper until a lucky fighting Arab in the eighth century of our era invaded Chinese territories.

The Arab was not slow in making known his discovery of this valuable substance for book-making. His nation at that time was just becoming a nation of scribes as well as of fighters; and how better could one of the Faithful serve his master the Prophet than by introducing a substance which would facilitate the promulgation of the true faith? His opinion was shared by the rest of his nation, and within a few years after this first discovery, paper-making was known all over the Moslem empire. The city of Damascus became the source of most of the paper in Christendom, and for this reason the substance was known as *charta Damascena* for many years.

For a long time the Moors in Spain were the paper manufacturers for all Europe; but after they were driven out by the Christians, their industry fell into the hands of the Spaniards. But the new proprietors were unskilful, and were slow in learning the art, so that the product of Moorish mills, once so famous for its quality, never again equaled its former standard.

MATERIALS FOR PAPER-MAKING

Most of the early papers were made from cotton pulp; linen and other fibrous substances did not come into use until several centuries later. Nor is there any definite record of just when the transition from one substance to the other took place. Our most reliable source of information at the present time is found in the specimens of paper themselves. These, when examined microscopically, show that wool was at one time a favorite substance for paper-making for certain purposes, but was usually mixed with other substances. Pure linen paper does not seem to have been manufactured until early in the fourteenth century; and cotton paper was used for several centuries before this, even for official documents, although parchment was the more common substance for this purpose.

Had man been able to take advantage of Nature's hints more readily, he might have been a paper-maker many centuries before he was. For Nature sometimes makes a paper from a pulp in a manner almost identical with the simpler process now employed by man. Man makes paper by beating fibers into a pulp, soaking, and then drying them. Nature does the same thing with the water-plant known as the "conferna." This plant, growing in long filaments at the bottom of pools, is disintegrated by the action of the water, rising to the surface as a pulpy scum. The winds and waves and currents churn this about until, mixed into a true pulp, it finally washes ashore and dries as a veritable sheet of paper. It is quite possible that the first paper-makers of the Flowery Kingdom took their cue to the discovery of paper-making from this hint of Nature; but if so they were more observing and receptive than their occidental neighbors.

Paper-making seems to have been introduced into France just at the close of the twelfth century, and as the successors to the Moorish paper-makers in Spain were making a mess of their work at that time, France became at once the center of manufacture for fine papers, with Holland as a good second. Indeed, these two countries held a monopoly of the fine-paper manufacture for at least two centuries. Then England entered the field of competition, and soon became a worthy rival of the other two countries.

MAKING PAPER BY HAND

The early process of paper-making, which is all but obsolete at the present time, was slow, arduous, and expensive. First of all was the difficulty of getting the material, rags, for making the paper, as new cloth was obviously too expensive, and as a sufficient quantity of rags from any limited locality was usually difficult to obtain. When obtained in sufficient quantities, however, these rags were moistened well, and piled in heaps in some warm, damp place such as a cellar, and left to decay for twenty days or more. By the end of this time the perishable portion would have fermented and decayed, leaving only the fibrin, or long elastic filaments. These were separated from the perishable portions by boiling, and finally beaten to a smooth pulp by mallets.

With the earlier paper-makers the color of the rags determined the color of the paper, as the chemical process of decoloring was then unknown. White paper, therefore, was very expensive, as white rags were not common. But later the process of using such chemicals as lye, lime, chlorine, etc., was discovered, and the price of white paper materially lessened.

When the beaten fibers had been separated from all foreign substances, the mass was placed in a vat and the proper amount of water added to form a pasty pulp. To make a sheet of paper from this the operator used a mold made of a fine-wire screen, or cloth, which was stretched over a light frame. Above this frame and corresponding to it in shape and size, was another called a "deckel." In using these frames the operator dipped the mold into the pulp, filling it even with the top of the deckel. This determined the thickness of the sheet of paper, the depth at which the mold was dipped determining the amount of pulp taken up, and consequently the thickness of the sheet. The water was then drained off through the wire or cloth of the mold by constant agitation, leaving the pulp as a spongy, soggy blanket.

The "watermark," or the distinguishing characteristic of most papers, was made by designs in the arrangement of the wires themselves in the molds. When the wire was woven like cloth a "wove" paper was made; when the larger wires crossed the smaller ones at definite intervals, a "laid" paper was the result; and these names are still in use for machine-made papers. Of course there was no limitation to the number of designs that might be used for watermarks, and these came into use at a very early date, and have proved valuable means of identification in hundreds of instances.

When the water had drained from the mold, leaving the blanket of pulp of sufficient tenacity so that it could be removed, it was taken from the mold and laid upon a sheet of felt. Other layers of pulp were placed above it, alternating with sheets of felt, until a "post," several quires in thickness, had been made. This was subjected to pressure until most of the water was removed, when the sheets of paper were taken out and hung over ropes or poles to dry. When dry this paper was very porous, being more like blotting-paper. To overcome this, the sheets were dipped in solutions made from boots, horns, hides, parchment clippings, etc., which filled the pores and made the paper non-absorbent. This was known as "sizing" and the solution used was called the "size." The paper so treated was then dried, and if an especially smooth surface were required, was rolled between metal rollers.

This process of making paper is all but obsolete at the present time, although a few hand-paper mills are still in existence. English banknotes are still printed on hand-made paper; but the American "greenback" is made by machinery. The essentials of the processes of hand-making and machine-making, however, are practically identical, the difference being largely one of method of application. Working under the old method, it took three men a day to mold and finish four thousand small sheets of paper, the process from start to finish requiring about three months. By modern methods, as we shall see, a forest tree, standing in its full vigor to-day, can be marketed as paper to-morrow.

MODERN RAG-PAPER

The discovery that wood pulp could be utilized for the manufacture of paper had a revolutionary effect upon paper-making machinery and paper-making methods—for certain kinds of paper. But no means have been found, as yet, to produce the finer grades of paper from wood pulp, or from anything else, save the time-honored but plebeian rag. Indeed the rag industry is almost as important to-day—perhaps quite as important—as it was when rags were the only substance used for paper-making. Thus we have the curious paradox of the stately forest monarch used only for the making of plebeian papers, while the despised rag eventually carries the watermark of royal stationery.

The rags used in the paper factories are literally collected from all over the world, and practically without any regard to condition. They arrive at the paper-mills in steam-compressed bales, frequently reeking with disease-bearing odors. The bales are sent at once to the machines called "openers," which tear them open and then pass them on to the "thrashers," which are huge cylindrical receptacles, revolving rapidly, supplied with long wooden arms or beaters. Here the rags are pounded and thrashed about, the dust and, in part, the odors, being carried off by suction air-tubes. Later they are sent to the sorting room where they are sorted as to size and condition, and all buttons, hooks and eyes, and ornaments or foreign substances removed. Here, also, machines with scythe-like blades, called "shredders," mangle and shred the larger pieces of cloth.

In the ordinary paper factory the work in this room is most unwholesome as well as disagreeable. In factories where only the highest grade of paper is made, however, this is not the case. For in such factories only the cleanest rags are used, and frequently only new rags, such as come from the clippings of shirt factories, and high-class tailoring and dressmaking establishments. Yet despite the fact that the subsequent treatment of all rags with steam, hot water, and chemicals renders them quite as "aseptic" as the new rags, most persons will find some satisfaction in the thought that the best papers on their desks are the remnants of new, rather than old, garments. It is also reassuring to know that "greenbacks" are made from new rags.

After the rags leave the shredding room they are sent to the "cutters," where they are still further cut and chopped to pieces. Here also the search for buttons and other foreign bodies is continued, large magnets being used sometimes for extracting metal buttons and other bits of iron or steel that may have escaped detection in the other sorting processes. The rags then pass on to a machine called a "devil," or "whipper," which is a hollow cone with spikes projecting within, where they are dashed about, and still more dust and dirt extracted, passing on finally to the "duster" for the final cleaning. This duster is a whirling conical sieve, with air blasts and screens, which remove the last vestiges of dirt and dust particles.

Obviously all the foregoing manipulations of the rags are simply cleaning processes, and really have nothing to do with paper-making proper. But with the next step—the introduction of the rags into the "digesters" —begins the real process of turning cloth fibers into paper. The machines in which this process begins are huge revolving boilers, frequently eight or ten feet in diameter and twenty feet high, with a capacity for five thousand tons of rags. These digesters contain a solution of lime and soda, heated with live steam, and here the rags are boiled under forty or fifty pounds' steam-pressure from twelve to fourteen hours.

By this time the fibers are loosened, as well as the dirt and colors, the contents of the boiler becoming a dark mushy-looking mass, that gives little promise of snow-white paper. This is because the foreign substances that have been loosened have not as yet been separated, this task falling to great tubs known as "Hollanders," after the country in which they were invented a little over a century and a half ago.

The "Hollander" is oval-shaped, usually about twenty feet long, nine feet wide, and three feet high. In these tubs are iron rolls covered with knives which revolve over a set of fixed knives below. When the rags are thrown in and the machinery started, a continuous stream of water is made to circulate about the tub. This carries the rags beneath the iron rolls and knives, which pull the mass to pieces and separate the fibers, which are thrown upon wire cloth where the water is drained off, taking with it the coloring matter, the rags becoming gradually whiter and whiter as the washing process proceeds. Bleaching material is then added, the rags becoming perfectly white in four or five hours. When this stage is reached the water is drained off, and the mass of white fibers is thrown into drainers until most of the water is removed, leaving a tough mass having the appearance of matted cotton.

When thoroughly drained, the mass of fibers is placed in the "beaters." These are machines with rolls and knives not unlike those in the "Hollanders" which draw out the fibers and separate them, and beat them into the paper pulp proper. If specially fine white paper is to be made, bluing is added to the mass at this stage, just as laundrymen use it for whitening linen.

The discovery of the use of bluing was the result of an accident some two centuries ago. The wife of an

English paper-maker named Buttonshaw, while watching a tub of pulp, accidentally spilled the contents of a bluing bag into the mass. Restraining her first impulse to call her husband, she decided to await the result before confessing. To her surprise, and to the astonishment of her spouse, the batch of paper coming from the tub containing the bluing was the whitest, finest paper ever seen; and brought an unusually high price in the London market. His customers demanded more paper of the same kind, but the puzzled paper-manufacturer was unable to meet the demand until his contrite wife confessed. She was rewarded with a new bright-red cloak, and from that time London was furnished with the finest white paper ever brought to market.

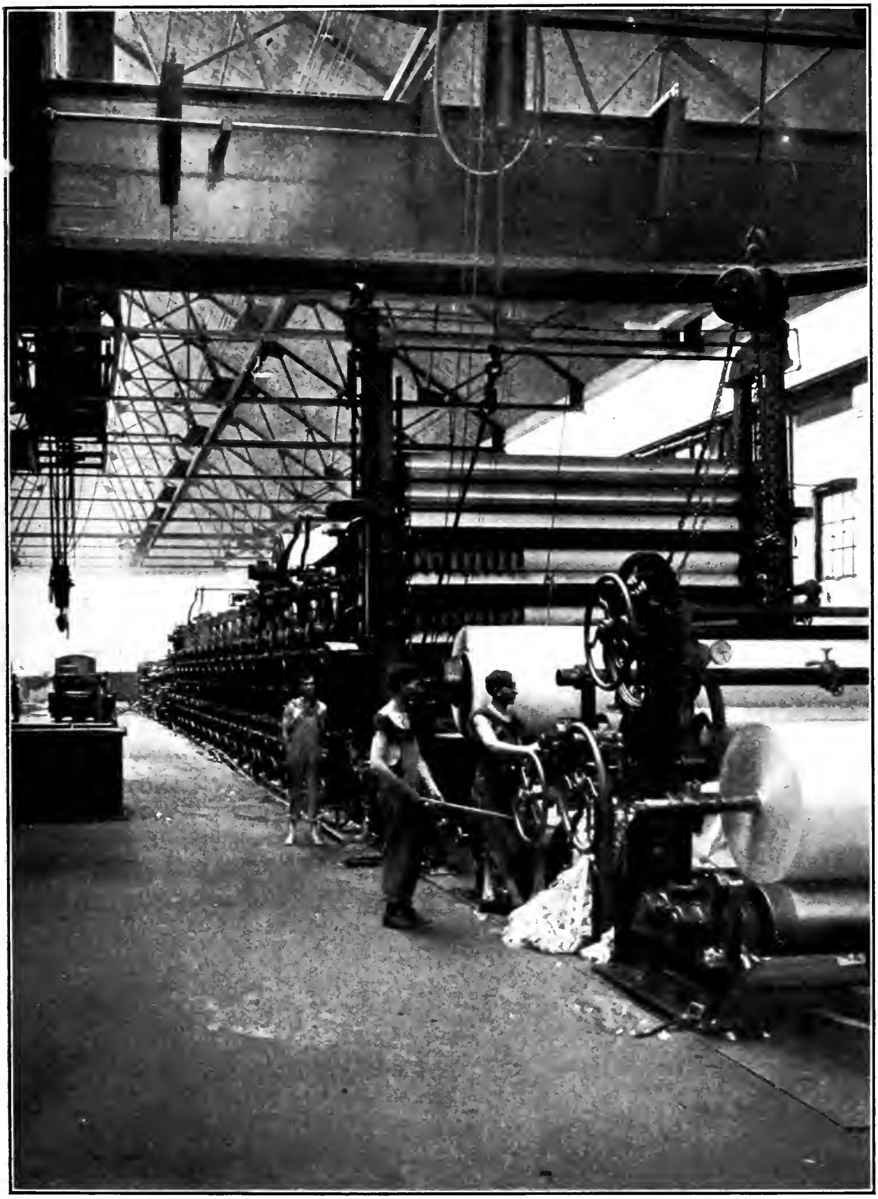
But bluing is not the only substance added to the mass of the pulp in the beater. Here sizing and body-coloring are added, and adulterations, also, if such are to be used. It is here that "loading" is done—that is, clay, or cheap, heavy fibers are added to make a cheap and opaque paper. Such a paper takes the cuts for illustrations well, but is weak and easily torn.

At this stage the pulp is an opaque mixture, of about the consistency of milk, and having very much the same appearance. It is, indeed, "liquid paper," for it is simply a mixture of paper fibers and water; and when the water is drained off the paper is left behind. But, as we have seen in the hand-process just described, this separation of fibers and water is a complicated process. Here the old hand-mold, on which one sheet of paper at a time was scooped out of the vat, is replaced by an endless wire cloth, upon which the paper can be made in rolls many miles long instead. The pulp is run up on this moving wire cloth in a layer of a certain depth, according to the thickness of the paper being made, the water draining through the meshes as it moves along, leaving a blanket-like layer of white pulp behind. This passes first under the "dandy roll," as it is called—a wire-cloth roll on which is woven the watermarks, designs, names, etc., which are to be distinguishing characteristics of the paper when completed. The impressions from this dandy roll remain more transparent than the rest of the paper, as can be seen by holding any sheet of watermarked paper to the light.

By the time the damp blanket of paper has passed the dandy roll it has acquired sufficient body so that it can be passed between two rolls covered with felt, which compress it slightly, pass it on to a belt of moist felt, which carries it to two metal rolls called the "press rolls." These compress it still more, send it along other belts and through still other rolls until it has acquired enough tensile strength to sustain its own weight—can "travel alone," as the paper-men say. It is then ready for its journey through the drying cylinders—from a dozen to fifty of them—great, steam-heated steel rolls, three or four feet in diameter, over and under which the web of paper travels until it is perfectly dry.

In this journey it acquires its full tensile strength, which contrasts remarkably with the delicate blanket of fibers that left the pulp-vat a moment before with scarcely more cohesive quality than mud. It still is, and it will always remain, a delicate substance, inasmuch as it may be torn easily between the fingers when held in certain positions, but it has most amazing strength when even tension is applied. "In evidence of this," says Butler, "may be cited an instance that seems almost beyond belief. Through some curious mishap a web of heavy paper, in fact, bristol-board, which had been thoroughly formed, was suddenly superheated and then cooled while still on the driers. This was caused by a difference in temperature of the driers, and resulted in the sudden contraction of the web of bristol; the strain on the machine was so great that not only were the driving-cogs broken on two of the driers around which the paper was passing at the moment, but the driers themselves were actually lifted out of place, showing a resisting power in the paper of at least several tons."

When the paper comes from the driers it may be regarded as finished for certain purposes; but if it is to be a smooth-surface paper there still remains the process of "calendering." The "calender" is an upright set of rolls, steam-heated, through which the paper is whirled at the same speed at which it passes through the other cylinders. In fact the entire process is a continuous one, the paper traveling at a uniform speed from the time it leaves the pulp-vat until it emerges from the last cylinder as finished paper. This speed varies, of course, with different machines and with the different kinds of paper, but a speed of from four to five hundred feet a minute is not uncommon—the trotting-gait of the average coach-horse.



MANUFACTURE OF PAPER

Showing the series of heated rollers over which the film of paper-making material is passed. The plastic mass of pulp entering at one end of the apparatus is transformed into paper and emerges as a finished product at the other end. The rolls of paper shown here are ready for the printing-press.

In most of the good grades of paper, such as ordinary writing paper, the sizing is done, as we have seen, by adding the sizing matter to the pulp. With some of the finer grades of paper, however, the sizing is done after the sheet of paper is formed, by passing it over and under rollers through a vat containing sizing made from horn, hide clippings, or some similar substance.

When a very hard, smooth surface of paper is wanted, there is an additional calendreing process besides the first one just referred to, known as super-calendering. The machine for doing this is a stack of rolls, a steel roll alternating with one of solidified paper or cotton, the stack containing from seven to fifteen of these rolls. In passing through these the paper acquires a hard, glossy finish. Considerable electricity is generated by the action of the calender rolls; so much so, indeed, that if not disposed of in some manner, it would interfere seriously with the working of the machine, causing the paper to stick, and gathering all manner of particles of dust and bits of dirt from the surrounding air and floors. To prevent this, ground-wires are usually laid to carry off the current.

PAPER FROM WOOD PULP

Until the middle of the nineteenth century there was very little change in the process of paper-making and in the kind of material used. But about this time printing-machinery began to make great changes and strides of progress, and the demand for cheap paper became imperative. The supply of rags could not meet the demand, and even if this were possible their price was prohibitive for ordinary papers. Substitutes were eagerly sought, therefore, and presently it was discovered that the fiber of certain kinds of woods, spruce and poplar in particular, was admirably adapted to making the coarser grades of paper. It was shown, indeed, that any but the very finest grades of paper could be produced from these fibers, particularly if "flavored" with a dash of the finer rag pulp. The result of this discovery was completely revolutionary in the paper industry; the sites for some of the great paper-making establishments, instead of being in the centers of population as formerly, were now removed to the wildernesses of the great spruce forests, where the material for making the pulp was at most only a few rods away.

For some time after the discovery that wood pulp could be used for paper-making, there was great difficulty in preparing the fibers economically. Machines for sawing and chopping the wood were tried, but they were not satisfactory; and when treated chemically the fibers in the wood resisted the action to such a degree that a great amount of time was required. Finally it was discovered in Germany that by grinding the wood with an ordinary grindstone, the fibers could be separated and turned into pulp rapidly and cheaply. It was this discovery that gave the great impetus to the wood-pulp industry; and it was this, perhaps more than any other single thing, that made possible the "penny newspaper."

It should not be understood, however, that only a newspaper quality of paper is made from wood pulp. All wrapping papers, most book papers, and even some of the good grades of writing-papers are now made from it. And it is probably only a question of time until some process will be discovered whereby the pulp of wood will be made to take the place of rag pulp, revolutionizing the prices of the finer grades of paper.

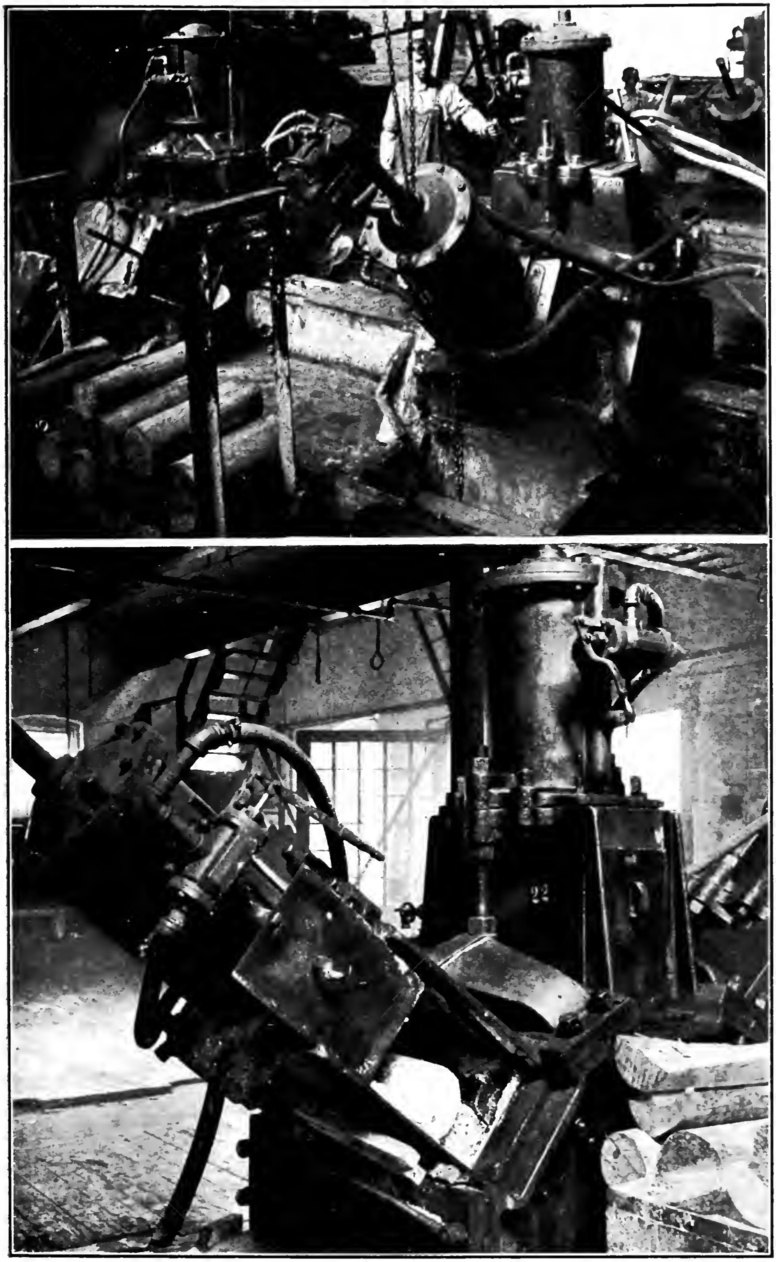
Even at the present time there are several methods of preparing the wood pulp in use besides that of grinding. The grinding process is the cheapest and most popular, but also the product is of the poorest quality, and the paper made from it is relatively weak. The several chemical processes in use produce a longer and better quality of fiber, and it is from some of these, rather than from the mechanical grinding process, that fine grades of paper may finally be made. Of these processes probably the "sulphite fiber process" is the most important at present.

"In this process the wood after being barked is cut into small chips, which are dissolved by boiling or cooking with sulphurous acid in large boiling-tanks or digesters. The product, after being washed and otherwise prepared for use, has a much longer fiber than a mechanically prepared pulp, and is used to give strength to papers in which that quality is required. News-, common wrapping papers, and some other grades consist chiefly of ground wood with twenty to twenty-five per cent. of this chemically prepared sulphite added to hold them together. Other grades, such as strong wrapping papers, are made entirely from sulphite fiber.

"This process is of American invention and was first used in 1867. Its early development was slow, owing to the difficulty of procuring the necessary apparatus. The strong chemicals employed penetrated the linings of the digestors as then constructed, eating into their shells and rapidly spoiling them for use; and until recently no species of lining has been found to resist the attacks of the acid and keep the digestors whole. Within a few years, however, linings have been invented which secure this end, and the sulphite process is now established as the leading method of securing chemical pulp.

"Soda fiber is ordinarily made from woods softer than spruce, chiefly poplar, and is a softer, mellower fiber, without much strength. It is used as a soft stock in book, and to some extent in writing-papers. Its preparation is similar to that of sulphite, except that in place of sulphurous acid a solution of caustic soda is used in the digestors. The process is older than either of the two just mentioned, having been introduced into this country from England in 1854. It came into extended use earlier than the sulphite fiber, but owing to the greater cheapness of the sulphite process in producing a strong cellulose fiber from spruce, the use of the latter has increased more rapidly than that of soda.

"The merchantable shape of these fibers differs somewhat. Ground wood is ordinarily sold in folded sheets only partially dry, and is, therefore, under common conditions only suitable for use near the locality of its manufacture, its weight being so increased by the water as to preclude the profitable transportation of such a low-priced product, on account of the freight on this



PULP-GRINDING MACHINERY

The sticks of wood are held "side on" by hydraulic pressure against a rapidly revolving grindstone. In this way the wood-fibers are reduced to pulp, from which paper is made.

extra weight. Sulphite is either sold in similar shape, first having had a portion of the water removed by pressure, or else dried by steam in rolls like paper. Soda fiber is ordinarily so sold, though sometimes in a partially wet state like sulphite."[2]

The process of making paper after the pulp is obtained from the grindstones, or from the chemical vats, is practically identical with the process used for rags. This is true also of the treatment of the other substances that are used for paper-making, such as flax, manila, jute, hemp, straw, and old paper.

Reference was made a moment ago to the kind of paper used by the government in the manufacture of banknotes, or "greenbacks," and it was stated that only new rags are used in their manufacture—the remnants from the establishments making linen goods. There is another peculiarity in this banknote paper with which most people are familiar, and which is a government monopoly, inasmuch as it is unlawful for any person to manufacture such paper. The peculiarity in question is the fact that this paper contains a large number of tiny silk-thread clippings, of various colors, and from a quarter to half an inch long. These may be seen in any new or clean bill by holding it to the light, and are placed there for the purpose of preventing counterfeiting.

These silk threads are inserted in the paper just after it leaves the pulp vat and is still a plastic blanket on the "wire" of the machine on its way to the cylinders. Just above the "wire" is a little conducting-trough, which sprinkles water holding the silk threads in suspension upon the web of pulp as it passes beneath. These threads are fed automatically to the trough, so that a uniform distribution is effected.

WATERMARKS AND SPECIAL PAPERS

A volume of interesting stories might be written about watermarks, and the important part they have played in romance, crime, and every-day life during the last five or six centuries since their discovery. Tales of forgeries detected and criminals apprehended, innocent persons liberated, and guilty ones imprisoned, would fill many pages of that interesting book. A fair sample of these would be the story of a famous forgery case of a century ago, involving a vast amount of property, where the case hinged upon a certain document which seemed to be authentic, but which was finally detected as a clever forgery by the watermark. It was definitely proven that the watermark of the paper on which the document was drawn was not used until several years after the supposed date of the document. From this mute but conclusive evidence there was no appeal; and no chance remained for a difference of opinion.

But cases of this nature have been discovered so frequently as to be almost commonplaces in the history of crime. Quite as interesting are the historical features of some of the ancient watermarks. For the process of thus putting an indelible mark upon paper has been known since early in the fourteenth century. The very first of these marks was in the form of a ram's horn; and later it was customary to use such commonplace objects as tea-kettles, beer mugs, jugs, etc., as watermarks. King Henry VIII showed his contempt for the Pope by using a watermark in his stationery showing a fat hog wearing a miter. "Fool's cap" is the name handed down from the time of Charles I, when a paper having a fool's cap and bells for a watermark was used in place of paper having the royal arms, in derision of the monarch. "Post" paper, which was watermarked with a post-horn, gets its name from the old paper that was made "letter size," convenient for folding, before the days of envelopes.

At the present time only the better grades of paper are given watermarks, and these are usually in the form of the names, or designs, of the manufacturers. The old custom of designating the kind of paper by such marks has fallen into disuse.

The development of photographic processes for reproducing pictures was responsible for the polished paper on which the now familiar half-tone is printed. Such cuts can be printed on almost any kind of paper with modern presses; but for the very best reproductions it is necessary to use a paper having a surface coated with a fine clay, and polished by calendering. Some idea of what a difference in results is made by the different papers may be seen by comparing the half-tone cuts in newspapers with those in the higher-class magazines. The newspaper cuts lack the contrasts of white and black, being of a more nearly uniform gray tone. Yet they may have been printed from the same half-tone cuts as the magazine illustrations. The difference in appearance is largely due to the difference in the paper used, although, of course, there is also a difference in the care used in printing the two publications.

It is possible to give a high polish to any good grade of paper by super-calendering; and while such a paper resembles the surface of a "coated" paper in general appearance, the coated paper can be detected by a simple test. If the finger is moistened and rubbed for a moment on the surface of any coated paper, the clay will be loosened and adhere to the skin in a thin film of powder. This will not occur with any other kind of paper; and this test can be made with any illustrated magazine, the pages having the illustrations being of coated paper, while the text pages, particularly if there are several together without pictures, are very likely to be of plain paper.

The clay used for making this coated paper comes from Cornwall, England, and is pure kaolin, or china-clay. This is ground to the fineness of fine flour, mixed with glue and spread on a body-paper, dried, and calendered. This coating-process is a special department of paper-making, and many large establishments, where coated paper is manufactured, do not make any of their own body-papers, but obtain them from other manufacturers.

The machinery for coating the paper is very simple. It consists essentially of a vat for holding the coating material—the "enameling solution" as it is called—some rollers for regulating its distribution, sets of brushes for working out lumps and still further regulating the distribution, and automatic carriers for taking the paper through the drying-room before going to the calenders. The calenders are the same as those used in the other processes of paper-making. When a web of paper is to be coated on both sides it is started on rollers through the enameling solution, emerging between two rolls which regulate the thickness of the coating and remove the surplus. Next it comes in contact with the brushes, arranged in sets so that the coarser brushes act upon it first, fine camel's-hair brushes giving it the finishing touches. It is then passed on to the automatic carriers, which take it through the drying-rooms heated to about 140° F. where it becomes perfectly dry before being sent to the calenders for the final polishing. The degree of polish given the paper depends upon the amount of pressure used on the calender rolls, and the number of times that the sheet is passed through the machine.

This paper is somewhat similar to the glazed papers used for covering boxes, and for making many fancy articles. But in these papers wax is added to the coating, giving it the familiar gloss.

SPECIAL USES OF PAPER

In recent years paper has been used for a greater variety of things than almost any other substance. Even to catalogue these would require a volume. And curiously enough these uses are as diversified and frequently as diametrically opposed to each other as possible. Treated in a certain manner paper may be used as tinder for lighting fires; or if treated by a different process the same fibers may be used as a component of fireproof substances, such as the drop-curtains in the theaters and the packing of engines. By proper manipulating it is made into soft, pliable, felt-like "chamois fiber," or compressed and hardened into an ideal material for car wheels. In short, it can be made to take the place of down, or steel, or almost any other substance of intermediate density.

When the manufacture of paper car wheels was announced a few years ago it was generally supposed that this was simply the experiment of some imaginative enthusiast. Few people took the announcement seriously. But in point of fact the paper car wheel has no rival for endurance and reliability. The cost of manufacture is its principal drawback. The process of making these wheels is as follows:—

"The material used is calendered rye-straw board, or thick paper, and the credit of the invention belongs to Richard N. Allen, a locomotive engineer. The material is sent to the car-wheel shops in circular sheets measuring from twenty-two to forty inches in diameter, and over each of these is spread an even coating of flour paste. The sheets are then placed one above the other until a dozen are pasted together, when all are subjected to a hydraulic pressure of five hundred tons or more. After two hours' pressure, these twelve-sheet blocks are kept for a whole week in the drying-room heated to a temperature of 120° F., after which a number are pasted together, pressed, and dried for a second week; a third combining of layers is then made, followed by a month's drying, until there is obtained a solid block, containing from one hundred and twenty to one hundred and sixty thicknesses or sheets of the original paper. The thickness is only from four and one-half to five and one-half inches, and in weight, density, and solidity the block resembles more the finest-grained, heaviest metal than it does the original paper product. It may be called car-wheel paper. To complete the wheel there are required a steel tire, a cast-iron hub, wrought-iron plates to protect the paper on either side, and two circles of bolts, one set passing through the flange of the tire, the other through the flange of the hub, and both sets through the paper. The paper blocks are turned on a lathe, which also reams out the center-hole for the hub; two coats of paint are applied to keep out moisture; the cast iron is pressed through by hydraulic pressure; the other parts are forced into place, and the paper center is forced into the steel tire by like hydraulic power; and there, a product of human ingenuity, is a paper car wheel, which never is injured by vibrations, and is safer and longer-lived, though costing more, than any other car wheel made."

But the wheels of cars are not the only part of the car that is sometimes made of paper. The boards for interior finishings, and sometimes the seats, are made from what is known as "paper lumber." This paper lumber is made by passing ordinary straw-board through a vat of resin and other waterproofing at a temperature of about 350° F., then placing a number of these sheets together and subjecting them to hydraulic pressure. Boards so made are usually about a quarter of an inch thick, of a dark, blackish color, and may be worked with the saw and chisel the same as ordinary boards. They are only adapted to certain purposes, and are relatively expensive as compared with common lumber. A very common use of such boards is for the perforated seats used in waiting-rooms.

A more useful substance, and a much more familiar one, is papier-maché, which has been used for various purposes for something like a century. Ordinarily it is made from waste paper, repulped and mixed with a strong size of glue and paste, to which chalk, clay, or lime is sometimes added. To make the finest papier-maché, strips of specially made strong paper are soaked in a strong size of paste and glue, molded into any shape required, and dried in an oven. They are then hardened by dipping in oil, trimmed, and japanned or painted, and made into one of a thousand different useful or ornamental articles, such as boxes, trays, artists' lay-figures, picture frames, and mural decorations. This substance is used also for certain kinds of roofings, and is a very excellent floor-covering.

The antithesis of these hard-paper products is the chamois fiber, just referred to. This is made from the long-fibered sulphite stock of the wood-pulp factory. As this pulp passes through a set of special machines the fibers are mangled and pulled about until the resulting fabric is a soft, flexible, chamois-like substance. It is impervious to air, is a poor conductor of heat and cold, and, as it wears fairly well, is sometimes used for making undergarments.

Obviously it would be useless to attempt even the mention of the useful articles that have become essential to civilization and that are the products of the pulp. Buttons, books, boxes, houses, canoes, cars, furniture, pails, barrels—almost everything, indeed, that one can think of or imagine. The case is covered by the statement of a recent writer, who said, "Since the introduction of wood pulp, paper figures, either wholly or in part, in more diverse and numerous articles than any other one substance known."

IX

THE REPRODUCTION OF ILLUSTRATIONS

THERE is hardly a more striking example of nineteenth-century advance in the methods of communicating ideas than that of modern processes of reproducing pictures. Fifty years ago an energetic wood-engraver, by working long hours every day for a month, could produce an illustration the size of one of the ordinary illustrations in the Sunday newspaper. The same sized illustration can now be produced, with more fidelity to nature, in an hour. And yet up to the time of the beginning of the last quarter of the nineteenth century this process of wood-engraving was the only practical way of reproducing illustrations for such publications as books, magazines, and newspapers. There were other methods of reproducing pictures, to be sure, such as etchings, lithographs, etc., but for the most part these cannot be used for ordinary newspaper or book illustrations. The wood-engraving was therefore the most important as it was the oldest form of reproducing pictures.

Just when or where wood-engraving made its first appearance cannot be determined. The earliest examples of wood-engravings now extant date from about the time of the invention of printing from movable types. It is probable, therefore, that wood-engraving, at least in a crude form, antedated this period by many centuries, although the impetus to book-making given by the introduction of the printing-press undoubtedly stimulated the development of wood-engraving; and the history of the making of reasonably good wood blocks begins with the history of the printing-press.

Of course, making impressions from engraved surfaces must be practically as old as carving itself, dating back to prehistoric times, since the principle involved in wood-engraving is practically the same as wood-carving and metal-chasing, where certain portions are removed, leaving other portions of the wood and metal on a level with the surface. It must have happened many times, therefore, either accidentally or otherwise, that the wood-carver or metal-worker made impressions on cloth or paper from his carvings. Such impressions are still made by metal-engravers from time to time as their work progresses, and there is reason to believe that ancient metal-workers were familiar with this method of printing their work. This being the case, it is probable that designs of carving or chasing were frequently copied by means of impressions upon cloth or leather, which of course is a rude form of printing from the engraved surface. But no records have been preserved showing that this method was ever used extensively in reproducing pictures.

By the beginning of the fifteenth century wood-engraving had reached a comparatively high state of development, and from that period on, thanks to the printing-press, there is no difficulty in tracing the advances made in the art. In fact the earliest types used in printing were simply wood-engravings made by digging out the wood about the letter, either separately or in words or sentences.

A simple illustration of the way in which a crude woodcut may be made is to write any word written in the ordinary manner with pen or pencil upon a block of wood having a perfectly even surface. If, now, the surface of wood about the letters is dug away, leaving the letters standing out in relief, it is obvious that a facsimile impression may be taken from this primitive woodcut by inking the surface of the letters and pressing a piece of paper upon them. An impression so made will of course be reversed, so that in order to have the woodcut reproduce the word in its correct form when printed, it is necessary that the word be reversed in writing it upon the block. This simple principle holds true in all wood-engravings, and for that matter practically all processes of reproduction, ancient or modern.

For many years a woodcut representing a picture of St. Christopher and dated 1423 was considered the oldest woodcut in existence. It seems practically certain, however, that there are a few examples of even earlier work than this, some of them having a date as early as 1406. In these woodcuts little attempt is made to reproduce lights and shadows, the figures being represented mostly by simple outlines. But in the woodcuts which appeared in great numbers shortly after this time, fairly successful attempts were made to represent lights and shadows of various gradations by the use of finer or closer lines, just as in modern wood-engravings.

It is obvious that if the surface of the block of wood is left untouched, it will give a perfectly black impression to the paper when inked. It is equally apparent that in portions that may be cut away from the surface of this block, it will show as white space on the paper. To produce a perfectly black spot, therefore, of any desired shape, the wood-engraver has but to outline this shape and cut away the surface of the block about it. Conversely, if he wishes to have the space of a certain shape remain perfectly white, he has but to dig out the surface of the wood in the desired shape. In producing perfectly black or white effects, therefore, there is little difficulty, and comparatively little skill is required. For intermediate tones, however, such as dark or light grays, the wood-engraver makes use of parallel or crossed lines, either wide apart or close together according to the tone he wishes to reproduce. It is obvious that if he wishes to reproduce a very dark surface he would leave the lines heavy and close together, or if he wishes to lighten these tones he would simply cut away more of the wood between the lines. In this way it is possible to represent a perfectly black surface gradually grading into a white one, simply by using parallel lines which gradually diminish in size until they finally disappear entirely.

This is the general principle which lies at the foundation of all wood-engraving, and no departure is made from it, except in the matter of skill in application, in a delicate woodcut of a Timothy Cole or a Henry Wolff of to-day, or the unknown engraver of the picture of St. Christopher in 1423, although this is not apparent in the finished product.

About the middle of the fifteenth century another method of wood-engraving called *criblé* came into use. In this method of engraving the wood was not cut away in lines as in the ordinary wood-engravings, the various tones being obtained by punching holes in the surface of the block. By this method all gradations in tones were obtainable, the results being not unlike coarse spatter-work or dotting, as done in certain kinds of pen drawings. This process, while giving excellent results, was extremely slow and tedious, and passed out of existence entirely a little later, except for certain purposes for which it is still admirably adapted. For astronomical charts, for example, where the sky is represented as a black background, and the stars as points of light of various sizes and in certain positions, the *criblé* method of wood-engraving gives excellent results.

The sixteenth-century wood-engravings were a great improvement over those of the preceding century, probably the best known being the pictures of Albrecht Dürer. Some of these are so skilfully engraved that they approach the perfection of modern engravings, although, of course, lacking in perspective and color-values which have become one of the essentials of modern illustration. From the time of Dürer, the improvement in wood-engraving was a steady growth until, by the beginning of the last quarter of the nineteenth century, it had reached its highest perfection. Then, about the year 1887, photographic-process reproduction made its appearance, and since that time wood-engraving has rapidly declined until, as a method of reproducing artistic pictures, it has practically disappeared except for special purposes.

TECHNIC OF WOOD-ENGRAVING

In making drawings for wood-engravings the artist usually drew directly upon the surface of the block of wood that was to be engraved. The wood used ordinarily was boxwood, cut across the grain. To facilitate working on this surface it was usually covered with a light coating of Chinese white, which enabled the draughtsman to see the effect of his drawing very much as it would appear on white paper when printed. This drawing was of course exactly the size that it appeared in print, the artist being thus greatly handicapped in a manner quite unknown to modern illustrators, whose drawings may be made any convenient size without regard to the size of the reproduction to be made.

Although the wood-engraver was obliged to produce his effects by means of lines, it was not necessary for the artist to indicate each of these lines unless he chose to do so. He might make his drawing on the block with a brush or pencil, indicating the shadings as he wished them, but leaving it to the artistic sense of the engraver to determine the direction and size of the lines used in interpreting the various shades and tones. It is obvious that when the artist drew in this manner the result obtained was due largely to the skill of the engraver, a good engraver frequently improving the original work of the artist while a poor engraver might ruin the work of a good artist. For this reason good engravers were at a premium, the best artists frequently working in conjunction with their engravers, or stipulating with publishers that only certain engravers should be allowed to reproduce their work.

As a natural outcome of this position of artist and engraver, disputes were constantly arising between the two classes of men, each claiming the lion's share of credit for a good illustration, or placing the blame upon the other in case of poor work. A characteristic attitude of the artist toward the engraver is shown in an expression of one of the artists illustrating for *Punch* in the early days. "Here is the drawing," he remarked; "now see the engraver spoil it"—which, as a matter of fact, he frequently did.

There was another method of drawing, however, whereby very little was left to the artistic skill and interpretation of the engraver. That was where the drawing was made in lines with a pen by the artist himself, the task of the engraver in such cases being simply to cut out the spaces between the lines. In this way the artist's work was reproduced with great fidelity, and the onus of the result obtained rested entirely with him. The engravers working upon this kind of drawings required relatively little skill as compared with the ones who determined their own lines for reproduction.

The amount of work and time required to make even small wood-engravings with a comparatively coarse line, will be apparent to anyone by glancing at a print of such a block. Every line, some almost microscopic in size, must be cut out carefully with an engraving tool. Not only is this a tedious task, but one requiring a great amount of mechanical skill, for even the slightest slip of the tool could ruin an engraving, or a considerable portion of it, that may have taken hours or even days to produce.

If only a single engraver worked upon a single large engraving, as he usually did in the best class of work, the time required to produce such a block was so great that for ordinary weekly, or monthly, periodicals, where timeliness is a determining element, its use was out of the question. To hasten the engraving-process, therefore, it was customary to cut the block into several smaller pieces after the artist had finished his drawing, turning over the pieces to a corresponding number of engravers, each of whom engraved the section of the picture assigned him. This was of course a great saving of time, as the blocks could be clamped together when finished, ready for printing, presenting the same appearance and giving the same result as in the case of the single block. In such cases the individuality of the engraver was, of course, lost—a most important element in fine engravings.

Waiving questions of the relative artistic effects obtainable by wood-engraving as compared with modern photographic methods, two other elements were determinative in deciding the question of the survival of wood-engraving when in competition with photographic processes. These elements are time and cost of production. The time consumed is of course commensurate with the cost where human labor is concerned, and the relative time of producing a wood-engraving as compared with a photographic block may be roughly represented in some such ratio as that of minutes to hours. This being the case, it will be readily understood that, from the commercial point of view, the wood-engraving must go out of existence. It has one advantage, aside from its mooted artistic superiority over certain forms of photographic engravings, in that it may be printed with reasonably good results on cheap paper and reproduced an almost endless number of times without deterioration. For this reason, in cases such as illustrations for advertising purposes, etc., in newspapers, which are to be repeated day after day in millions of impressions, the wood-engraving is still used, the elements of time and cost of production being unimportant. On the other hand such engravings have little advantage for such purposes over the modern "zinc etching," or "zinco," as it is vulgarly called, to be referred to more fully in a moment, which may be produced so much more quickly and inexpensively.

COPPER- AND STEEL-PLATE ENGRAVINGS

Shortly after the time of the introduction of the wood-engraving, and possibly at a much earlier period in its crudest form, reproduction of pictures made from engraved metal plates came into use. The method of engraving such plates and of printing them was exactly the converse of the process of wood-engraving, although this is not shown in the finished prints. In the wood-engraving the part of the surface designed to make the impressions of the ink upon the paper is the part left by the engraver, the hollowed-out part between the lines not being touched by the ink, and therefore represented by the white paper in the reproduction. With a copper- or steel-plate engraving, however, the hollowed-out lines of the engraving represent the black lines in the finished picture, those hollowed spaces taking the ink from the roller or pad and conveying it to the paper, the surface of the plate not taking the ink. A good example of this kind of engraving is the plate of the ordinary calling, or business card, as anyone may observe by inspecting his plate.

This kind of engraving is supposed to have been first introduced by a goldsmith of Florence some time in the fifteenth century, although, as noticed before, it was probably used for certain purposes much earlier. It was customary for these metal-workers to bring out the sharp outlines and effects of their carving upon the gold by filling the spaces made by the engraving tools with a kind of black enamel. In this way the beautiful designs cut in the metal were sharply outlined by contrast. These engravers, wishing to take impressions of their work from time to time, were in the habit of covering the surface of the engraved metal with some kind of coloring matter, wiping the excess from the surface, and making their impressions by pressing paper over the surface so treated. In this manner it was discovered that designs of the greatest delicacy could be transferred to paper; and from these tentative attempts the process of reproduction by copper and steel plates finally developed.

Copper as the softer and more easily workable metal was the one generally employed, but the durability of the steel plate once it was finished made it preferable for certain purposes. The popularity of this kind of engraving was greatly increased by the interest taken in the process by some of the great painters, particularly those of the fifteenth and sixteenth centuries. In this process such artists as Dürer, Rubens, and Raphael saw the possibility of multiplying and distributing a great number of copies of their paintings and drawings, and giving them a wide circulation all over the world. It also offered a means of preserving reasonably accurate representations of their work which might otherwise be accidentally destroyed and lost, or, being sold and removed to some distant city, would be lost to the artist except as a vague memory. For this and other reasons all the artists of that period encouraged the line engraver, some of them being skilled in the actual technic of the engraving-process itself.

Most of the great painters, however, confined their efforts to directing the work of the engraver rather than to undertaking the tedious task of cutting the metals themselves. For this work, like the work of the wood-engraver, was done with a pointed chisel, or sharp tool, called a "burin," and each line to be reproduced represented a corresponding gouging-out of metal with this implement by manual labor.

In the nineteenth century, steel-engraving for reproducing pictures very generally supplanted copper-engraving; but both of these methods of reproducing have gone out of use except in certain cases where, in special editions of books or pictures, the publisher finds it advantageous to revive this practically obsolete form of illustration.

ETCHING

A form of engraving which became popular perhaps a century later than the line engraving and which is still popular, particularly among artists, is the etching. In this process, as in the copper plate, the lines which are to be reproduced are cut into the surface of the metal. But the actual cutting is not done mechanically with a tool but is accomplished by a chemical process, after such lines have been indicated on the waxed surface of the plate.

In preparing such an engraving the etcher covers the surface of the copper plate with a specially prepared compound of wax smeared over the surface in a thin layer. This wax is not affected by the actions of acids, whereas the copper may be quickly eaten away by them, or "etched," to any desired depth. By using a pointed needle, therefore, which will scratch away and remove any portion of the thin layer of wax that it touches, surfaces presenting corresponding lines of copper may be exposed, which will be eaten out of the surface of the copper, as pressed by the needle in the wax. In this manner the mechanical effort of cutting out lines is entirely done away with, and the artist is free to make his drawing upon the waxed surface of the copper with a pointed instrument which may be moved about with the greatest freedom. It is possible, also, to correct errors when made before the acid is applied, by resmearing the surface with wax and making over again the drawing at this point.

The advantage of the etching lies in the fact that, owing to the minuteness and freedom of the lines, it is possible to produce most artistic effects. These qualities especially appeal to the painter, and many of the great painters have also been great etchers. Of the older masters, Rembrandt and Van Dyck were famous for their etchings; and in recent times such men as Whistler and Seymour Haden have been great exponents of this kind of engraving.

MEZZOTINT

There is another form of metal-engraving, called mezzotint, which was invented in 1643 by Van Siegen, a Dutchman, though erroneously ascribed to his pupil, Prince Rupert. This is a mechanical process like the copper-plate engraving rather than the etching, but in which the line, made by a pointed instrument like the burin, is not employed, the plate being prepared and worked upon in a peculiar manner. To prepare a plate for mezzotint work a peculiar instrument is used, this instrument having the edge ground into the segment of a circle, and so engraved as to present something like a hundred minute teeth. When this "cradle" is pressed upon the surface of copper and rocked back and forth, a great number of minute dents will be made in the copper, each dent, of course, raising a corresponding burr. In preparing such a mezzotint plate the surface of the copper must be worked over something like a hundred times, the cradle being worked in different directions.

When finished, such a plate presents a surface which, if inked, presents an absolutely black tone. For producing the desired effect of outlines, and lights and shadows, upon such a plate, the engraver scrapes away with a point, or scraper, such portions as he wishes for forming the outlines, controlling the tone by light or heavy scraping as the case requires. This process is of course a most tedious one, but the results obtained from a good mezzotint more nearly resemble effects in nature than any other form of reproducing before the introduction of photography. Prints from the mezzotint plate had to be very carefully made, and only a comparatively small number could be obtained from a plate, the pressure of the paper soon wearing it out.

THE INVENTION OF LITHOGRAPHY

The process of printing illustrations, letters, or diagrams by lithography is one in which stone is used in place of wood or metal, as in the case of wood-engraving and line engraving. The process of preparing the stone, so that certain surfaces will print while others will not, is done in several ways. In a general way, portions of the stone which are to come in contact with the paper are raised above the surrounding surface by treating their surfaces with some substance not acted upon by an acid, and then biting away the surrounding stone to the desired depth. Another method of accomplishing this same thing, however, is by treating the surfaces of the printing portion with some substance that will absorb printing-ink, while the surrounding stone is kept moist with a substance that does not absorb the ink. In this way the antagonistic qualities of grease and water are made to take the place of the raised surfaces in printing. Still another method, practically the same in principle although somewhat different in application, is to blot out on the stone certain portions which are not to appear in the printing, leaving the exposed surfaces for absorbing the ink and transferring it to the paper in the process of printing. These apparently simple processes are subject to endless variations and, of course, require a great number of complicated details in practical lithography. The principle involved, however, is practically the same in all kinds of lithography.

This method of reproducing pictures was discovered near the beginning of the nineteenth century by Alois Senfelder, a native of Prague. Senfelder, being an ambitious but very poor playwright, had made various experiments in attempting to reproduce pictures for his writings in order to save the expense of wood-engraving. Having occasion at one time to write some notes, and finding no paper at hand, he wrote these notes upon a slab of stone which he used in grinding his ink. As it happened, the ink used in this writing was of a composition that would resist the action of acid. A few days later, when about to erase this writing from the stone, it occurred to Senfelder to treat the surface with an acid to see what the effect would be. The result was most surprising, for at the end of five minutes the stone had been eaten away to the depth of about one one-hundredth of an inch, leaving the lines of the pen strokes raised in relief sufficiently to receive ink from a pad or roller. Fortunately, Senfelder remembered the composition of the ink used, and recognizing the possibilities of this entirely novel and rapid method of reproduction, he began a series of experiments and made numerous improvements so that by the time of his death, in 1834, he had brought lithography to a high state of perfection.

Of course this method of reproduction does not lend itself to illustrations in which the pictures are to be incorporated with type, as in the text of books and magazines, for the lithographic stone is necessarily too large. But for certain classes of work, lithography is still extensively employed, and since it lends itself to a combination with photographic processes, it seems likely to continue in use for some time to come.

Only certain kinds of stone are suitable for fine lithographic purposes, such stone being the very hard, homogeneous limestone which is found mostly in Germany, although stone of inferior quality may be obtained in several other countries. The surface of the stone is prepared according to the use for which it is designed, sometimes being polished perfectly smooth and at other times roughened very slightly or in a very coarse grain. When thus prepared, the artist makes his drawing with lithographic ink or with a special pencil or crayon made of some substance that will resist the action of the acid. In this way lights and shades may be represented in line on the polished stone, or may be indicated as tones with a crayon or with a pen on the roughened stone, the grains of which retain small or large quantities of the lithographic chalk according to the pressure used. If, for example, the artist wishes to produce a light-gray effect, he may do so by rubbing the crayon lightly over the surface of the stone, and he may intensify this shade to any desired degree by increasing the amount of pressure, thus depositing more of the acid-resisting substance; or he may produce a flat black effect by covering the surface of the stone with ink.

It will be seen that in this process the lights and shadows are not reversed, the lithographer drawing and shading them in the same manner as would be done in an ordinary drawing, although the composition of the picture is reversed. One of the features of lithography is the remarkable results that may be obtained by its use in color-printing. In principle this printing with many colors is simple enough, but when it is considered that for every color used a separate stone and a separate printing on the same piece of paper is necessary, registered so accurately that there will not be the slightest variation in its position as it is placed on the successive stones, the results shown in the finished color-print seem little short of marvelous.

When a colored picture has to be duplicated by lithography, the lithographer first determines how many colors will be required to produce the desired effect. An outline of the picture is then made of exactly the right size on a stone, and the patches of color are carefully outlined. This stone, which is known as the keystone, determines the exact position of each of the colors as they will appear on the separate stones. Suppose the picture to be reproduced is a simple one, using, let us say, five colors. This will necessitate the use of five separate stones unless, as often happens, colors can be produced by superimposing them or by combining more than one color on a single stone. The artist will then select a color, red, let us say, noting from the keystone every patch of red as outlined there. In exactly the same positions on another stone the outlines for the reds are made, of corresponding shapes, omitting all other parts of the picture. On a second stone he will treat the outline of the blues in the same manner, on a third stone the yellows, and so on until each color to be used is represented on the stone in a position so that if the colored inks are applied and a piece of paper in an exact relative position to each stone is successively pressed upon each of these stones, a picture in five colors, practically duplicating the original, will be produced.

Of course if each of these patches of color on a stone were simply outlined, leaving a perfectly flat surface for printing, with the remaining surface of the stone cut away by the acid, the result would be a perfectly flat mass of color for each patch so treated. As shading is usually desired, however, this is produced with chalk or pen as described a moment ago, dark patches of color being indicated by heavier marks and the lighter ones by correspondingly lighter marks.

In recent years aluminum has been used extensively to take the place of lithographic stone. On this metal the inks can be worked well, and its lightness and relatively small bulk have brought it into general favor. In the same space occupied by a single lithographic stone a great number of aluminum impressions can be stored, so that the matter of storage space alone becomes an important factor.

THE INTRODUCTION OF PROCESS WORK

In all the methods of reproducing pictures that have been described so far, the artistic skill of the engraver or lithographer has played an important part. Any workman to be successful in producing illustrations by means of any of these methods must not only have acquired a certain degree of perfection in mechanical skill, but also have considerable artistic ability. As a combination of these two qualities is rarely found in the individual who has chosen engraving as a calling, it followed that good reproductions of pictures which really interpret the work of the artist satisfactorily, were only produced by a limited number of high-priced workmen.

On the discovery of photography by Daguerre, whereby chemical rather than mechanical means were used for reproducing representations of natural objects with more fidelity than by any method previously known, attention was directed to applying this new process to the reproduction of pictures. For many years these efforts were not successful, but about the beginning of the last quarter of the nineteenth century, it was discovered that a mixture of albumin and bichromate of potash could be hardened by exposure to light, this hardening varying according to the intensity of the light, the resulting hardened substance not being acted upon readily by acids.

If, therefore, a copper or zinc plate were covered with a film consisting of a mixture of fish-glue, albumin, and bichromate of potash, and portions of it so covered that they were not acted upon by light, while other portions were exposed to it, it was found that by treating this plate chemically and then placing it in an acid bath, the portions exposed to the light retained their original surfaces while the covered portions were eaten away. In other words, an engraving could be made in this manner. It made no difference as to the size of the surfaces covered or exposed to the light, a thin line being protected against the attack of acid by the hardened bichromate mixture as readily as a white blotch. If, for example, lines in black ink were drawn upon a surface of glass, and this glass placed over a sensitized copper plate and exposed to light, the lines would appear as depressions in the plate when treated with the acid, as the ink would protect the thin film of the sensitized medium from the light. On the other hand, if this drawing upon the glass were reversed so that the lines made by a dry pen or point appeared as transparent lines, like scratches on smoked glass, such lines, allowing the passage of light, form hardened lines in the bichromate mixture, and, when the plate is treated with the acid, appear as raised surfaces like the printing-lines of a woodcut. In short, if the artist's drawing were scratched upon a glass covered with an opaque substance, an engraved reproduction of his drawing could be made upon zinc or copper plates by the process just described.

In actual practice such a method of drawing is difficult to use and is not practical, but by making use of photography the same effect may be produced if the drawing is made in the ordinary method with pen on white paper. For the negative made by the camera reverses the lights as they appear in nature, the black lines on the white paper appearing on the photographic negative as transparent lines on a black background—like the scratches on the smoked glass, just referred to.

Such a negative is then placed over a sensitized zinc plate and printed in the same manner as the photographic plate. The light passing through the openings in the glass plate corresponding to the lines of the drawing hardens the bichromate mixture beneath. The zinc plate is then "rolled up" with an ink-roller carrying an acid-resisting ink, placed in water, and developed. Wherever the light has penetrated the hardened bichromate mixture remains, the other portions being washed away. The plate is then dried and strengthened by a resinous powder, and after being slightly heated is placed in the acid bath.

In this manner a drawing may be reproduced with the greatest fidelity, every pen stroke of the artist appearing exactly as it was made in the original. Here was a process that was at once rapid, cheap, and absolutely accurate, and this is the method in use today for reproducing pen drawings as used in newspapers and other publications.

This discovery was the first great blow to the wood-engraver, who could no longer hope to compete with so simple and rapid a process which, in the end, interpreted the work of the artist fully as well, if not better, than the woodcut. And most of the artists themselves preferred this method for reproducing their work, having, among other advantages, the ones that the artist was no longer restricted as to size in making his drawing, and also that he need no longer reverse figures and composition. He was at liberty to follow his natural tendencies in drawing, whether large or small, the size of the reproduction being determined by the camera and consequently being made large or small with equal facility.

THE HALF-TONE

This "line block," "zinc etching," "zinco," as it was variously called, had practically every advantage of the wood block, and could even be used on coarser paper. But, like all other preceding forms of engraving, it could not produce gradations in tones except by lines and dots. Such surfaces as photographs, for example, could not be reproduced directly, but must be redrawn in pen or crayon. Any picture where tones were produced by lines, however, or even very minute dots, could be reproduced by this "direct" process. Even the minute and almost microscopic dots of a lithograph picture or a pencil on coarse paper could be reproduced, and by using hard metal, such as copper, and printing carefully on fine paper, even the very fine lines of an etching could be reproduced also. In fact, most of the so-called "etchings" scattered broadcast at present in cheap publications are really only "zinc etchings," which are about the cheapest, instead of the most expensive form of illustration they would be if they were real etchings.

This form of reproducing pictures, known as the "direct" method, was soon succeeded by the discovery of a method employing the same principle but which could be used in reproducing such flat-toned pictures as the photograph. This ingenious process, perhaps the most wonderful as well as one of the simplest processes of reproduction, is what is known as the "half-tone" process, made so familiar in the last two decades by the illustrated magazines of every description, in which most of the pictures are made in this manner.

This process differs from the foregoing in that a "screen" is interposed between the picture and the negative in making the "screen negative" for printing on the metal plate to be engraved. For this reason the half-tone process is called the "indirect," in contradistinction to the "direct" one. The principle of producing gradations in tone is accomplished by fine dots or lines in the one, just as in the other, only these dots are made artificially upon the negative and not on the picture itself, and are so minute that they are not noticeable except by careful scrutiny.

If an ordinary piece of wire screen, such as is used on the screen-doors in summer time, is placed in close contact over a picture of any considerable size, it will be observed that, while the picture is somewhat obscured, it is still easily discernible; and if it is held at a little distance it appears almost as distinct as without the overlying screen, the meshes of the screen practically disappearing. Obviously, a large surface of the picture is no longer visible, being covered by the fine wires of the screen; yet the general effect remains the same. It is evident, therefore, that the visible parts of the picture actually seen are minute square spaces of various grades of tones and colors, each one represented in size by a mesh of the screen. The picture in this condition is simply a mosaic made up of a number of small squares.

If each one of these squares is examined separately it will be found that the tone of each is practically uniform, sometimes slightly darker on one side or the other as the tone of the picture grades from dark to light. This surface, then, is one of dots—the kind of a surface necessary for reproduction by the direct photo-engraving process just described.

Observing this and similar phenomena it seems to have occurred to several engravers, shortly after the discovery of the direct process of engraving, to attempt to produce such an effect with very minute dots of a fine-mesh screen upon the negative to be engraved. And this was finally brought to practical perfection by Dr. Max Levy, of Philadelphia, who invented a machine with which almost microscopic, but still uniform, parallel lines could be ruled upon glass.

If anyone will take the trouble to hold any half-tone picture close to his eye he will observe, what may not have been apparent at the ordinary reading distance, that the picture is made up of innumerable small dots. This is the effect of the screen, and the homogeneous surface of color is really an aggregation of minute dots of color—a great mosaic, just as in the case of the picture with the wire screen over it. These dots, so inconspicuous but still the substance of the picture, are made by the glass screen which is the all-important agent in half-tone reproduction processes.

This screen is made of two pieces of glass, ruled with minute parallel lines, so placed that they cross at right angles, giving the mesh-like appearance of the screen. To prepare such a screen, the surface of a piece of glass is coated with some substance analogous to the coating used on the surface of the metal plate by an etcher. This surface is then ruled by delicate machinery in minute parallel lines, the diamond ruling-point of the machine removing a minute line of the coating, but leaving a corresponding ridge of it between each line. These lines are at mathematically equal distances apart, and there are from about fifty to as many as four hundred to the inch. When ruled, the surface of the glass is treated to an acid bath, which eats out the surface of the glass in the paths made by the diamond point. When sufficiently etched the glass is cleaned, and an opaque pigment rubbed into the rulings. Another plate, treated in a similar manner but with the rulings running at right angles, is now fitted to the surface of the first one, the result being the checkered appearance seen in the half-tone print.

To reproduce a picture by means of this screen, an ordinary negative is made just as in direct photography, except that the screen is interposed between it and the picture or object to be photographed. The resulting negative, which is called the "screen negative," shows the minute meshes on the screen, just as observed in the finished print.

This negative is now laid upon a copper or zinc plate and treated in the same manner as the zinc etching just described. As the minute rulings of the screen were filled with a dark pigment that prevented the passage of light, it is obvious that the layer of sensitized film will be acted upon in minute checks representing the meshes of the screen. When this has been acted upon for a sufficient length of time, the copper plate is removed, inked, developed, and washed, this washing removing all the particles of the sensitized coating not hardened by the light. The plate is then dried, heated, and subjected to an acid bath which "bites" away the intermediate surface of copper about the dots. The plate thus finished is mounted type-high, and may be inked and printed in the same manner as ordinary type.

Of course, in the actual practice of making fine half-tones the process is somewhat more complicated, although not differing in principle. For example, the engraver, wishing to produce lighter or darker effects, "stops out" certain portions, and "bites" others longer, to get the desired effect. But these are details, and this process has made it possible for an ordinary workman, having neither artistic taste nor any great degree of mechanical skill, to produce in a few hours, or even minutes, an engraving which gives a more faithful and natural reproduction of drawings or objects than is possible by the most skilful wood-engraver after weeks of hard labor. Furthermore, any number of such engravings may be made from the same negative.

The result of the discovery of this simple process with its wonderful effects was the finishing blow to wood-engraving, and except for certain ultra-artistic and commercial purposes, wood-engraving has become a thing of the past. The skilful wood-engraver of the older generation has been obliged to seek other means of earning a livelihood, although one field is still open to him to a limited extent. This is the "retouching," or engraving, of the half-tone plate itself. It is found in practice that for very fine printing the half-tone plate can be greatly improved by engraving certain portions of it with a tool, just as in the case of the wood block. Good half-tone printing must be done on paper specially prepared with a surface to get the desired color-values in printing from the ordinary acid-etched plate. To facilitate this printing, and to get the best results, therefore, the plate is sometimes "tooled" in places, the tooling of such blocks having now become the regular occupation of many former skilful wood-engravers.

In the actual process of printing, the etched plates themselves are usually not used, duplicates of them made by "electrotyping" being generally employed, the original engraved plate being kept in reserve. This electrotyping-process is a simple one, it being possible to make as many duplicates as desired without injury to the original plate. To make such electrotypes an impression of the engraved plate is taken by pressing it firmly into wax or some other similar medium. The result is an exact cast of the engraving in the wax. This cast is then placed in an electric bath containing a solution of copper, from which the copper is deposited upon the surface of the wax as a thin film of metal, by the action of the electric current. This film of metal, which is an exact duplicate of the original plate, can now be strengthened by pouring lead or type-metal over its posterior surface, and is then ready for mounting type-high and printing.

THREE-COLOR PROCESS OF REPRODUCTION

Perhaps the most wonderful result of the discovery of reproducing pictures by the half-tone process is the possibility of reproducing pictures in color by the comparatively simple process of superimposing three half-tone blocks successively upon a surface of color. The underlying principle, which is the basis of all three-color work, is the well-known fact that all colors, and all shades of color, may be produced by proper blending of the three primary colors, red, blue, and yellow. This is of course not apparent to the sense of sight, and the ordinary painting, with its purples, greens, and browns, to say nothing of the blacks and whites, seems to be an aggregation of scores of colors having little relation to each other. But as a matter of fact this is an optical illusion, the seemingly endless varieties of colors being simply blendings in certain proportions of the three primary colors. This optical illusion is no more wonderful than the fact that ordinary white light, which appears to have no color at all, is in reality a blending of many colors; but from the nature of the case it is more tangible.

As early as 1861 the possibility of producing any desired color by superimposing the primary colors in exactly the right proportions was suggested by the

English scientist, J. Clerk-Maxwell, but in actual practice many difficulties were encountered in producing the desired effects by such a process. A great number of things interfered with the actual workings when it came to apply pigments to the paper. For example, the colors used must necessarily be absolutely pure reds, blues, and yellows; and such colors, containing no trace of any other color, were difficult to produce. A great difficulty was also encountered in the mechanical part of producing practical blocks for printing. So that it was not until 1881 that practical color-printing became possible.

Experimenters both in Europe and America had been working on the problem, but the first blocks that were actually practical for this kind of work were perfected by F. E. Ives, of Philadelphia, in 1881. This date, therefore, with that of the discovery of the half-tone process shortly before, marks an epoch in the history of illustration—an epoch of perhaps greater improvements than any since the discovery of the possibilities of reproducing pictures by woodcuts or metal plates.

Knowing that every picture in color, no matter how complicated its scheme, is simply a peculiar arrangement of the three primary colors, it is obvious that if some kind of substance which would allow the passage of the rays of one of these colors and exclude those of the others, could be found, then the position and amount of this particular color might be determined. This of course is not possible by the ordinary sense of sight any more than it is possible for the unaided eye to determine the composition of ordinary light. But by the use of prisms in such an instrument as the spectroscope, as is well known, this analysis of the composition of substances may be made. Acting upon the knowledge of these facts, attempts were made to produce transparent "filters" which, when used in connection with a photographic plate, allowed one of the primary colors of a picture to act upon the plate while excluding the other two. These experiments finally proved successful with the result that practical filters were made, allowing the transmission of the rays of any one of the three primary colors while excluding the others. Such filters were made in various ways, sometimes of transparent colored glass, or glass coated with some substance of the required tint, or again of a hollowed glass containing a liquid of the proper color.

In using these color filters, or screens, in the actual process of three-color work, the photographer makes three separate negatives, taking each from exactly the same position, one negative being made with a yellow filter placed between it and the picture to be reproduced, a second with a blue, and the third with a red. These negatives are developed and three separate half-tone blocks made from them, each block representing by its gradation of light and shadow the amount of yellow, blue, and red, respectively, contained in the picture. The blocks are then placed in the press and printed successively upon the surface of paper, using yellow, blue, and red ink, the result being an exact reproduction of the original picture with the colors faithfully produced, if sufficient time and skill are used.

Theoretically it makes no difference which color is printed first, or the order in which the other two are superimposed upon it; the result should be the same in any case, as the total amount of pigment covering any point in the picture will be the same. In actual practice, however, owing to mechanical difficulties, and for other reasons, this order of imposing the blocks is of great importance, the best results being obtained by certain definite order in printing certain pictures which would be less satisfactorily reproduced if this order were reversed.

It is obvious that one of the great difficulties in such a process is that of determining the exact shade of yellow, red, and blue pigment to be used in the printing, but this is usually done by practical experiment. Another difficulty is the matter of accurately registering each block so that it prints in exactly the same position as the other two. But these difficulties have been practically overcome so that at present three-color pictures of mediocre quality can be made with relative cheapness and expedition; while fine pictures faithful in color and extremely artistic in effect may be produced at a relatively low price.

Most good three-color engravers have their own special methods of making filters, and preparing and printing the cuts. In skilful hands a great latitude is allowable in the selection of colors for the different filters, inks, etc., and many engravers prepare their own filters and inks. One prominent firm, for example, uses green, violet, and red filters, and produces beautiful effects by this combination.

A great difficulty is always found in producing clear, snappy blacks and clear intermediate grays. To do this a fourth printing with black ink is sometimes used, the "three-color" work then becoming really four-color printing. The principle involved, however, is the same as in three-color printing, the extra black being applied to improve the blacks in the picture which have a tendency to become muddy, and not clear and sharp.

The comparative merit of pictures reproduced in color by lithographic processes and those reproduced by the three-color process is determined, commercially at least, by the fact that only three printings are necessary for the reproduction of any picture by the photographic process, whereas to get the same effect by lithography it is always necessary to make several more separate printings than these, sometimes as much as forty separate impressions for very fine facsimile work, although of course such a number is unusual.

Waiving the question of mechanical advantages or disadvantages, however, it may be said in a general way that artistic effects are better represented in the three-color process, a certain hardness in the colored lithography being practically unavoidable. For the reproduction of purely artistic designs such as paintings, therefore, artists very generally prefer the three-color process to the lithographic.

On the other hand, when exact facsimiles in color are to be made, where scientific accuracy rather than artistic effect is desired, lithography is still superior to three-color process work. The remarkable results that may be obtained by this lithographic process of many printings are such that in cases where an absolute facsimile is desired, regardless of cost, it is possible to produce such a facsimile so closely resembling the original in every particular that it requires the eye of an expert, sometimes aided by the microscope, to distinguish the original from the print. Some of the ancient Egyptian documents, for example, have been so faithfully reproduced, both as to the color and design of the papyrus as well as the painting upon it, that only by the closest scrutiny can the difference between the original and the lithographic copy be detected.

There are two distinct fields, therefore, for three-color and lithographic color-work. The perfection in lithographic printing, in its particular field, produces results which are as yet not attainable by any other method. Three-color work, on the other hand, is in its infancy. But it has been making such rapid strides during the last ten years that no one at present is warranted in predicting the limits of its possibilities. Even now it has practically driven lithography out of certain fields; and it may be only a question of time, and perhaps a very short time, before it will supersede the older process in every field.

The process of three-color work as just described represents the general method in use, and the principles involved. Needless to say there are endless variations in details in applying the process. In some of these processes the half-tone screen is in use; in others it is used only in certain parts of the picture; but the number and variety of these variations do not affect the general principle involved and need not be dwelt upon here.

INTAGLIO PROCESSES

The best representation of the older intaglio process of reproducing pictures is a steel-engraving where the printing-surface is set below the surrounding portion of the field, rather than the reverse as in the case of the ordinary printing-block. Perhaps the best modern representation of this process is what is known as the photogravure. And in many respects the photogravure may be said to hold the same relation to the modern half-tone that the steel engraving does to the woodcut of former times.

The photogravure, like the copper and steel plate, is made by digging out certain portions of the metal plate, but the process of doing this is no longer a purely mechanical one, modern photographic and chemical methods being requisitioned for the purpose. In making the plate for the photogravure a screen is used, but this screen is not made of ruled glass as in the case of the half-tone, but is one in which the necessary dots are produced by a fine layer of bitumen dust. In this process the fine dots made by the bitumen dust take the place of the little checks or points made by the half-tone screen.

As a photogravure is made with a depressed printing-surface instead of the ordinary raised one, a positive is used for printing in place of a negative. The metal plate so treated is then placed in a bath of some such substance as perchloride of iron which bites out the metal to the desired depth.

The prints made by this process present a fine granular surface and more closely approach facsimile reproductions than perhaps any other form. But the making of such prints from photogravure plates is a slow task requiring special printing and considerable skill, making such reproduction too expensive for use as ordinary illustrations. Furthermore, since each picture must be printed separately, the photogravure process cannot be used in connection with type.

While the majority of photogravure processes are based on the principle of the sunken printing-surface, it is possible to reverse this, making the photogravure plate as relief work. In this process the granular effect is obtained by the use of the bitumen dust the same as in the other, but the relief effect is obtained by certain processes of depositing particles of metal rather than by biting out surfaces with an acid. There is little choice between the results of these two methods.

Quite recently several secret processes of reproducing pictures have been invented which represent a middle ground between the relatively slow and expensive photogravure process and the cheap and rapid half-tone. The results obtained by these processes are somewhat inferior to photogravure work, while the expense and speed involved in their production compare favorably with a better class of half-tone work. The exact method of producing such illustrations is not generally known, but it is understood that no new principles are involved, and the secret lies mostly in the perfection of the printing-machine rather than in any new departure from well-known engraving-processes.

In the foregoing description of the development of the various processes for reproducing illustrations, only the broadest general principles involved have been touched upon, giving only sufficient details to illustrate the application of these principles. A complete account of the various modifications in the applications of these principles to practical engraving would require many closely written volumes, for almost every engraver has his own special method of doing things to get certain well-defined results, but these, although somewhat interesting in their details, are not essentials of the development of engraving.

X

PHOTOGRAPHY IN ITS SCIENTIFIC ASPECTS

IN the development of photography, at least, history has repeated itself under peculiarly similar circumstances. Two of the most important discoveries in this field, one made by Daguerre early in the nineteenth century, and the other by Becquerel just at its close, were made quite accidentally, and in practically the same manner. Becquerel discovered radio-activity, and Daguerre discovered a practical method of developing photographic plates, by accidentally leaving photographic material in a dark chamber.

The fact that certain chemicals quickly change color when exposed to light was known for half a century before practical photography was invented, the Swedish chemist, Karl Wilhelm Scheele, having discovered this about 1780. Curiously enough, it was this same scientist who discovered that color could be removed, as well as produced, chemically, both these discoveries being of the greatest commercial importance. In experimenting with the silver salts Scheele found that the color of a solution containing these salts could be changed by rays of ordinary light, or by light passing through blue glass, although the color was not affected by light passing through red or yellow glass. A few years later, Count Rumford, the discoverer of the fact that heat is a form of motion, attempted to show that the changes in chemicals attributed to the action of light by Scheele were really due to the action of heat; but he was unsuccessful in these attempts, Scheele's contention being strengthened rather than weakened by Rumford's arguments.

The first practical application of Scheele's discovery to picture-reproduction seems to have been made by Thomas Wedgwood, a member of the famous Wedgwood family, of England, in 1802. His process, which was first described in the Journal of the Royal Institution, was to moisten paper or white leather with a solution of silver nitrate in a dark room, and then expose the moistened surfaces to sunlight. In this manner the colorless moistened portions of the sheets quickly became black if exposed to the full rays of the sun, although they could be kept indefinitely without change of color if screened from the light. This discovery suggested the possibility of reproducing pictures, or "shadowgraphs," as they were called, and Wedgwood pointed out the advantages of such a process in reproducing prints from transparencies on glass.

Here was the germ of the idea from which practical photography has been evolved. But there were still many intermediate discoveries to be made before even the crudest photographs were possible. At that time there was no means of forming a camera-image, or "negative," the nearest approach to a camera being the camera obscura in which an image was shown upon ground glass. Nevertheless the possibilities of the discovery were recognized, and Sir Humphry Davy made some experiments with the camera obscura; but nothing like satisfactory prints could be made, and as no means of "fixing" the prints had been discovered, Wedgwood's discovery was looked upon as valuable simply as a scientific demonstration.

TENTATIVE EFFORTS

But the possibilities of this discovery, and similar ones that might result from it, stimulated scientists, and guided the trend of thought along channels leading to photography. Within the next decade these efforts bore good fruit. By 1814, a Frenchman, Nicéphore de Niepce, had discovered a method of making permanent photographs by a crude and complicated process. He coated the surface of a metal plate with a solution of oil of lavender, which, after being allowed to dry, was exposed to an image made in a crude camera. After such an exposure lasting several hours a faint image appeared on the plate which could be intensified and strengthened by a complicated process of development with more oil of lavender and bitumen. But even at best only a very faint image could be thus reproduced, although these first pictures of Niepce are very properly regarded as the first photographic pictures ever made.

The process of actually making these sun-prints was not revealed for some time by Niepce, who recognized the possible commercial value of his process if perfected, and made his experiments secretly. His task proved an arduous one, however, and it was another full decade before he had accomplished anything like practical results. Then, having perfected and improved his process until he was able to make pictures on metal in many ways resembling the modern tin-type, he sent an account of his discovery to the secretary of the Royal Society of London, together with some specimens of his work. But the actual process by which the pictures were made was not revealed in this document, and on this account the Royal Society as a scientific body, although greatly interested, could not publish it.

Just at this time a fellow countryman of Niepce's, whose name was later to be far better known in the history of photography, became interested in the subject. This was Louis Jacques Mande Daguerre, a scene-painter, who was famous at the time for his handling of lights and shades, and whose attention had been directed to the subject of photography by the remarkable effects he was able to produce with light projected through colored glasses. At that time he had done nothing with the subject of "heliographic pictures," as they were called, but when a letter came to him from Niepce, in 1827, suggesting that a partnership be established between them, he readily entered into such an arrangement.

The new firm was soon able to reproduce pictures of various kinds on metal, and also upon glass and porcelain, but the process used was too complicated and tedious for practical commercial purposes. Nothing but stationary objects in bright sunlight could be reproduced, and then only after weary hours of exposure to a sensitized plate in a camera. Ordinary landscapes required an exposure of from seven to ten hours—practically a whole day, although "this time could be shortened by half in the case of such objects as white-marble monuments."

THE DAGUERREOTYPE

This process was so exasperatingly near a really practical method of making pictures that Daguerre and Niepce strained every nerve to bring it to perfection, or at least to a stage of commercial practicality; but after six years of ceaseless struggle, Niepce died, leaving the riddle apparently as unfathomable as ever. Yet, had he but known it, he was on the very threshold of the discovery; and five years later Daguerre finally accomplished what Niepce had missed by so narrow a margin. In 1839, Daguerre announced to the French Academy the process that was thenceforth to be famous as the *daguerreotype* process, by which a camera image could be reproduced by the action of light and chemicals alone, and by a relatively short exposure.

The announcement of this process created a sensation in the Academy. There was no doubting the evidences of their own senses, and all the members were apparently in accord in their expressions of admiration and astonishment. Arago, the leading physicist of France, spoke in glowing terms of the possibilities of the new discovery, and made predictions as to its future usefulness that have been more than fulfilled in recent years. And as the French Academy had given the cue, other learned bodies all over the world echoed its sentiments. Nor were the scientists the only persons to recognize the possibilities of the new art. Quite as much interest and enthusiasm were shown by the generality of people all over the world, although as yet the process was so complicated as to be quite beyond the grasp of the ordinary operator. But anybody could understand that there was something closely akin to the miraculous in any device, no matter how complicated, whereby a more perfect picture could be made in a few minutes than could have been made hitherto by any known process in days or weeks.

And yet, as said a moment ago, the process was only a slight modification of the one first discovered by Niepce —slight, but of most vital importance. It was simply the discovery that if a silver surface, or a silver-plated one, was acted upon by the fumes of iodine, it became so sensitized that it was acted upon more quickly by light than any substance heretofore discovered. Instead of requiring hours of sunlight exposure to reproduce the camera image, only about three minutes were required by the new process; and even interiors could be taken in half an hour.

As compared with the older method of Niepce this process seemed rapid indeed; but it was still very complicated and defective in many ways, and it was while endeavoring to simplify and shorten it still more that Daguerre accidentally stumbled upon the discovery that made commercial photography possible. Being interrupted in his work one evening, he was obliged to leave some exposed but as yet undeveloped plates until the following day before completing them. For safekeeping he locked these in a cupboard containing chemicals of various kinds. On examining them the following morning he found to his astonishment that they were completely developed, although nothing had been done to them since their exposure. There was only one explanation possible: the fumes of some of the chemicals in the cupboard must have been responsible. And by a careful process of elimination Daguerre finally determined that the fumes of mercury had produced the effect. Carrying these experiments a little further he found that by exposing his sensitized plate in the ordinary manner and then holding it face downward over a basin of warmed mercury, the image appeared quickly, and could be made permanent by dipping the plate in a solution of hyposulphite of soda. This may be considered the starting-point of modern photography.

As there was no secret about the process used in making these photographs, scientists all over the world were soon duplicating Daguerre's experiments. Before the eventful year closed, two Americans, Morse and Draper, had succeeded in making a portrait of a person —the first ever taken. In making this first portrait the operators powdered the face of the sitter and posed him in bright sunlight, with eyes closed, for a period of half an hour. Several attempts were made before anything like a satisfactory result was obtained, the great difficulty encountered being the strain of the glaring sunlight upon the sitter's face, which was almost unbearable. Finally a glass jar containing a blue-colored solution was placed between the face and the sun, and the strain relieved in this manner, so that a fairly good, if somewhat ghastly, portrait was made.

TALBOT'S "CALOTYPE" PROCESS

Meanwhile another European scientist was making important discoveries in the same field that were to prove quite as momentous a little later, as those of Daguerre. Fox Talbot in England, about the time that Daguerre announced his discovery, discovered a process of photographing on paper, which he called "calotype" or the "beautiful picture" process. This did not differ very greatly in general principle from the process of Daguerre, save in the fact that paper was used in place of metal plates. But Talbot's "calotypes" were the forerunners of modern paper photographs, just as daguerreotypes are the direct ancestors of modern negatives.

In Talbot's process, the surface of the paper was prepared by brushing it over with a solution of silver nitrate, and allowing it to dry. It was then dipped in a solution of potassium iodide for two or three minutes, until silver iodide was formed, and was then treated with a solution of what is known as "gallo-nitrate of silver." If the paper so treated were exposed to the camera image for a few minutes, this image would be reproduced, as in the case of the silver-surface plates of Daguerre, the developing-process being hastened by soaking the paper in more of the gallo-nitrate solution. The paper was then washed thoroughly, dipped in a solution of potassium bromide for a few minutes, and again washed and dried, a permanent paper print, or photograph, being the result.

Although a little later it was decided by a legal technicality in a lawsuit that the patent rights of this process, and therefore presumably the priority of discovery, belonged to Fox Talbot, there seems to have been another and earlier discoverer of a "gallo-nitrate" process. This was the Rev. J. B. Reade, a clergyman who had become much interested in the new studies of light-pictures. But the courts decided the case in favor of Talbot on the ground that Reade's discovery had never been legally published; and, all things considered, this decision seems an eminently just one. For the gallo-nitrate process as used by Reade, although an important part of the Talbot process, was by no means the entire calotype process as Talbot perfected it. And while Reade's discovery may have helped Talbot, it was by no means responsible for his final results.

There is no reason to believe that Talbot ever attempted to belittle the part taken by the clergyman in the discovery of the gallo-nitrate process, for at that time the name Fox Talbot was too well known in the scientific world to need further advancement by claiming the work of others. It may be recalled that it was he who, with Rawlinson and others, helped to decipher the Assyrian hieroglyphics—a feat quite as wonderful as were his discoveries in photography.

Naturally, the thing most sought for in this new field of art-science was some substance that would render plates more sensitive, and, in 1841, an experimenter by the name of Goddard made the discovery that bromine vapor acted in this manner. In this same year, also, M. Fizeau invented the process of toning or gilding photographs with a solution of gold, greatly increasing the richness of their tones. There were, besides these important discoveries, a number of minor ones that helped in developing the process. But still it was too complicated for anyone, other than a trained scientist, to attempt successfully—was, indeed, still in the experimental stage, and of little account commercially. But just before the century turned the half-way point, another important discovery was made which placed practical photography within the grasp of any ordinarily intelligent operator, even one without any special scientific training.

GLASS NEGATIVES

This discovery, or invention, was that of the now familiar glass negative, from which prints could be made. The inventor was Niepce St. Victor, a nephew of Daguerre's partner, who had been trained by his uncle, and who had continued the investigations begun by the elder Niepce. In his experiments he used glass plates sensitized by iodized albumen, and obtained fairly satisfactory results; but this process was soon improved by Blanquart and Le Gray. The essential part of their process consisted in treating a glass plate with a mixture of the whites of eggs containing potassium iodide and potassium bromide. This solution was first dried on the plates, and was then sensitized by treatment for a few minutes with a solution of nitrate of silver. Such plates were exposed to the camera image while still wet, and then developed in a gallic-acid solution. They were extremely delicate and liable to injury before being dried, but when once fixed and thoroughly hardened were practically the same as modern glass negatives. Still, there was a tendency for the film to peel from the glass during the necessary manipulation, and this was not overcome until the following year, when Frederick Scott Archer, of London, discovered a means of remedying this by the use of collodion. This substance made a film so tenacious that it could be handled without fear of injury. Indeed, it may be said that it was this particular discovery, rather than the preceding, that made commercial photography possible.

While these various improvements in photographic plates were in progress, lens-makers had been busy with the improvements in cameras; and by the time the Archer collodion plate was perfected there were good cameras in which to use it. The entire process of photography was still a complicated one, judged by the modern standard of dry plates and "daylight developers"; but it required patience rather than skill or scientific training, and within a few years after Archer's announcement of his discovery almost every city, town, and hamlet over the civilized world, had its "photograph gallery." Indeed, the "craze" was quite as universal at that time, as was the similar one half a century later when the "push the button" snapshot-camera came into existence.

The cardinal defect of the collodion process lay in the fact that the plates had to be freshly made and kept in a moist state while using. This meant that the photographer could only operate near his dark-room laboratory, where he used his various chemicals. Field operations, therefore, were seldom attempted. But, in 1854, Spiller and Crookes published in the *Philosophical Magazine* the account of a method of keeping plates moist for several days that made field operations possible. The basis of this process was the use of the salts of zinc which have the property of imbibing moisture from the atmosphere. By incorporating a certain quantity of these salts in the moist film of the plate, drying was prevented for several days. So that by using a somewhat large and clumsy set of plate-holders, specially made for the purpose, the photographer could make extensive excursions; and field photography soon became popular.

COLLODION-EMULSION PROCESS

After the discovery of this last phase of plate-making little progress was made in photography for a decade. Then, in 1864, Bolton and Sayce invented their "collodion-emulsion process," and a new impetus was given to the art. It will be recalled that in the processes for coating the plates, used heretofore, it was necessary to coat the plate with the collodion mixture of the bromides, dry it, and then dip it in a solution of silver nitrate. In the new "emulsion" process the emulsion contained all the chemicals for the necessary reaction, so that the plate could be made simply by pouring the emulsion over the surface and allowing it to set. But, when first introduced, this process was found to have a serious defect—the plates frequently "fogged" in the developing process in an unaccountable manner. But this was soon corrected by the discovery of two Americans, Cary Lea of Philadelphia, and W. Cooper of Reading, Pennsylvania, that all this could be overcome by the addition of a little acid to the solution.

It was presently discovered that the addition of the acid made the plates much more rapid, although anything like "snapshot" photography was not possible. But in 1873 Col. Stuart Wortley found that when a strongly alkaline developer was used, plates need only be exposed a fraction of the time ordinarily required, although, as yet, such time for exposures did not cut the second into thousandths, as at present. This discovery had a peculiarly stimulating effect upon both scientists and practical photographers, and other important discoveries followed in rapid succession.

The following year, a famous Belgian chemist, M. J. S. Stas, published an article entitled *Researches with Chloride and Bromide of Silver*, in which he pointed out that bromide of silver could exist in at least six different states, each state having peculiar properties and different sensitiveness to the action of light. But this paper was written from the standpoint of the chemist rather than that of the photographer, as Stas himself was not personally interested in the art; and for the moment it went unnoticed by the photographers. In point of fact, however, it contained the key to the scientific facts upon which modern rapid photography is based; and a few photographer-scientists, recognizing the possibility of the suggestions contained in it began

THE FLYING MACHINE OF MR. GLEN H. CURTISS

This is a wonderful example of instantaneous photography. The machine appears to be stationary, although in reality moving at the rate of almost fifty miles an hour. With this type of machine Mr. Curtiss won the International speed contest at Rheims, France, August 28, 1909. He made a flight of twenty kilometers (12.42 miles) in 15 min. $50\frac{3}{5}$ sec.

experiments along the lines it suggested. Among these was Dr. D. von Mockhoven, of Ghent, and five years later, in 1879, he announced a process of making rapid dry plates by adding a solution of ammonium bromide to the ordinary gelatine emulsion that had very generally replaced the collodion emulsion by that time. This process he credited to the suggestions made in Stas' paper of five years before, calling attention to this important document in the history of photography that would otherwise have been generally lost sight of.

It is from this year, therefore, that we must reckon the beginning of rapid dry-plate photography. By this time the wet collodion plate had practically disappeared, replaced by the dry gelatine plate; and Mockhoven's discovery, with those of other scientists and practical photographers, made possible the fraction-of-a-second negative, and paved the way to the "You push the button" camera.

The modern era of photography may be said to begin with the discovery of Mockhoven and his associates. Yet one more step was necessary to give photography the impetus for becoming the popular fad that it has remained for the last fifteen years. This step was the stroke of genius of the man who conceived the idea of using a flexible transparent film in place of the ordinary glass-plate negative, and rolling a number of these into a coil so that several pictures could be taken without bothering with plates—the "kodak" idea, that has since carried the world by storm. This happened about 1888, and the amazing flood of improvements—cartridge cameras, daylight-loading cameras, daylight-developing machines, and a score of other innovations—that have come into the market since that time, are so familiar to the majority of persons that it seems superfluous and unnecessary to dwell upon them here. It will be consistent with our purpose to consider, instead, another important though much less familiar field, which may at any time be brought to a stage of practical perfection that will make the present-day methods seem as antiquated as those of Daguerre do to-day. I refer, of course, to the methods of so-called "color photography."

PHOTOGRAPHING IN NATURAL COLORS

To the average layman the idea of the photography of color is probably some method by which the color of objects may be reproduced as correctly and as automatically as are the shapes, and it must be stated at once that such a process, while the subject of much search, has never been even partially discovered, nor have scientists been able to discern any course of procedure that would lead to this end.

A recent writer on the subject has summed up the present status of the photography of color, which, as he states, is "always a compromise."

"The methods of both the past and the present naturally fall into two classes. The less important division includes methods in which a single homogeneous surface is employed, while in the larger division the surface is multiple or non-homogeneous. The first is generally an attempt to get as near as possible to the simple color photography" (that is, such a process of actual color reproduction as is mentioned above), "while the second is entirely indirect in that it does not aim at producing color at all, but only at automatically locating suitable dyes or inks." [1]

Thus, we must understand from the outset that the term "photography of color" is entirely a misnomer. Color never has been, and perhaps never will be, photographed. Nevertheless, extremely interesting and valuable results have been obtained by means of the above-mentioned "compromise," and as the recent perfection of processes has brought color photography well within the amateur's field of activity, the subject is worth some detailed consideration.

Alexandre Edmond Becquerel, a French physicist noted for his researches on light, seems to have been the first to take up specifically the matter of color photography. He began in 1838, although he did not give the world any account of his achievements until ten years later. Becquerel took a silver plate and produced on its surface, by chemical and electrolytic means, a layer of silver chloride. With the plates thus treated he succeeded in reproducing "with a considerable measure of success the colors of brightly dressed dolls and highly colored designs besides the solar and electric-arc spectra," but the colors were not permanent, and the investigator could find no means of "fixing" them satisfactorily.

What was the nature of these colors—were they actual pigmentary matter due to a change in the surface coating, or were they "interference" colors produced by "standing" light waves? Before answering this question it may be necessary to explain what a "standing" wave is.

If light waves in motion are reflected back in the direction from which they come, it is evident that the returning ones will constantly meet those that are advancing. At the points of contact, therefore, a series of waves, whose crests rise and fall but cannot move in either direction, owing to the counteracting of the forward and backward impulses, will be produced. These are the standing waves. At such stationary points the light will be interfered with or quenched, and thus there will result a "series of layers of light with intervals of darkness half a wave-length apart."

Now, several scientists, among them Zenker, of Berlin, believed that this interference or quenching of light was the explanation of the colors on Becquerel's plates. The German physicist explained that "the silver-chloride coating of the plate is so affected by the light that metallic silver is produced in layers with intervals of no chemical change which correspond to the parts where the light is quenched by interference." He assumed, and his assumption was afterwards proved to be correct, that metallic silver was produced because the successful reproduction of the colors required a strong reflecting surface, and he further developed his theory by stating that these silver layers of high reflecting power reflected "only, or chiefly, light of the same wave-length (or color) as the light which produced the layers when they are illuminated by white light." In other words, Becquerel's colors were merely the result of an intricate incidence and reflection of light, with the consequent interference, and not pigmentary matter at all.

Without going into the discussion, which was long and very technical, it is only necessary to state that it has been finally shown that "the colors produced by Becquerel's process were found to be chiefly interference colors due to the action of the standing waves, but there was pigmentary matter also present," the latter being due to the subchloride of silver, though why "this should be changed by colored light into a substance that has some approach to the color of the light that falls upon it is a problem still unsolved."

Prof. Gabriel Lippmann of Paris, in 1891, proposed a direct method of color photography, which, like that of Becquerel, is based on the production of interference layers in a photographic plate having a film sensitive to all colors and a good reflectory surface to send back the incident light. This surface was obtained by a slide filled with mercury which backed up the film. The results were never entirely satisfactory although the process was improved upon by later experimenters. It required very delicate adjustments and long exposures. This method must not be confused with the newer process of Professor Lippmann, announced in 1906, which will be described later. It is of quite another nature.

In 1861, Clerk-Maxwell demonstrated the possibility of projecting colored objects by means of three colored plates, red, yellow, and blue, basing his experiments upon the fact that all colors in nature may be simulated to the eye by a proper blending of these three colors. If three-color filters, made respectively of these three colors, were used, and negatives made by means of them, it would seem theoretically possible, at least, to reproduce colored objects by staining the three negatives thus made, red, yellow, and blue respectively, and superimposing them so that they are accurately registered. As a matter of fact that is what is really done by many of the most successful three-color photographic processes —practically the same method as used in three-color process printing, referred to in detail in the chapter on three-color printing.

In the actual practice of three-color photography many difficulties have to be overcome, and it is at best a tedious process. Three exposures must be made, and in making these the camera must be in exactly the same position for each negative. For a long time the difficulties to be overcome in this seemed insuperable, but Mr. F. E. Ives, of Philadelphia, has invented a slide-carrier for this purpose which works admirably; and Mr. Sanger-Shepherd has invented a single-lens camera by which all three negatives are taken at a single exposure.

The length of time for exposures with the different color-filters is important, and the time required is much longer than for ordinary normal exposures. Generally speaking, exposures through the blue filter are about a hundred times more than normal length, the green or yellow two hundred times, and the red three hundred times. If the normal exposure were ten seconds, therefore, the total time required for exposures through the color-filters alone, without deducting any time lost in changing, would be something like an hour and three quarters. But this time is not constant, and as a rule test-negatives are made and developed with various filters before the final negatives are taken.

It is obvious that when the negative is exposed to light coming through each of these filters, impressions will only be made and necessary deposits formed in development, at such points indicated by the position of certain colors. When such negatives are developed, only such positions of the object appear as are represented by the color in question. If positives are made from such negatives, and these stained red, green, and blue, respectively, according to the filter used, a transparency of the object photographed may be made, reproducing the natural colors with great fidelity.

Sanger-Shepherd and others have perfected a process whereby prints may be made from these positives by the use of colored inks. The gelatine representing the primary color on each plate is slightly raised, and will absorb the ink as required. By carefully registering each of these impressions beautiful colored photographs may be made. To reproduce and print such colored photographs, however, is quite beyond the range of the ordinary amateur photographer.

Generally speaking, all indirect color photography is based upon some such artificial and arbitrary separation of color, and the achieved results have been obtained by working in two different ways; first, by the production of three images, one for each of the required colors, and, second, by the production of a single image taken and looked at through a tri-colored film.

With the three images or records made by three exposures through colored screens, there are, again, two ways of forming the picture. By means of a set of three optical lanterns, each giving one of the required colors, the image may be thrown, superposed, upon a screen, the combination giving a colored representation of the photographed object; or the three records may be directly superposed. The latter is the basis of three-color printing, as we have seen.

The combining of three negatives by means of an optical lantern—thus obtaining views in natural colors—is an important branch of color photography, though its practice is attended with considerable difficulty, especially in the matter of matching the plates to secure the right effect when combined. The whole process, however, has recently been simplified to a considerable extent by a French scientist, M. André Chéron. He has devised a three-lens camera which takes the three views (one with each color screen) upon a single plate and at one operation. But the ingenious thing about M. Chéron's apparatus is that it serves as the lantern as well. A lantern transparency is made from the negatives and this is placed in the camera in the portion occupied by the original photographic plate. A lamp, Welsbach burner, or any good light serves to project the three images, and these pass through a large condensing lens placed in front of the camera lenses, thereby superposing the images upon the screen.

But all the while that the three-image process of color photography was being developed, efforts were made to obtain a satisfactory method which would do away with the necessity for these separate negatives and the consequent optical lantern.

"Forty years ago Ducos du Hauron suggested the production of a screen-plate as forming a simple method of color photography, which consists of a sheet of transparent paper mechanically covered upon its surface with three kinds of colored stripes or divisions. Writing of this method Du Hauron said: 'Let us imagine that one covers the surface of the paper on the side where the color stripes are imprinted with a preparation which gives, directly under the influence of light, a positive proof, and that one receives on its reverse side—namely on the side not covered with stripes—the image of the camera. It will happen that the three single colors will filter through the paper and form each its positive print, that is, its print in light of the corresponding ray of color, and the three prints will be formed with the same rapidity, in spite of the unequal degrees of actinism of the three simple colors, if one has been careful to give each of these three sorts of stripes a relative translucency, inversely as to photogenic power of these same colors on the preparation employed.'"

It is obvious that the colors must be distributed over the proposed surface in quantities so minute that when viewed by the eye they would be merged together just as are the details of an engraving. Du Hauron made his suggestion in 1868, but it was not until 1895 that the first screen-plate process was put forward commercially. The credit for this belongs to Dr. Robert Joly, of Dublin, although Mr. J. W. McDonough in America produced a practical screen-plate about the same time.

On Joly's plates "the three colors were arranged regularly in lines, and were applied to the glass by means of a ruling-pen. . . . . Joly used two color-screens—a 'taking screen' that was fixed in front of the plate while the exposure was being made, and a 'viewing screen' which was put in front of the positive for viewing the picture, and might be bound up with it as a fixture, if preferred."

By the use of ruling-machines, lines so fine that forty could be put in a millimeter (more than a thousand to the inch) were obtained, but even with these it was not felt that the desired degree of tenuousness had been reached.

Several other methods of making line color-screens have been devised, of which two, perhaps, are worthy of attention. One is the recent invention of Robert Krayne. "Sheets of celluloid are stained in the requisite colors and are then placed on the top of each other and cemented together so as to form a continuous block of red, green, and blue celluloid. A section is then cut straight through this block, and a leaf obtained which shows through its width the red, green, and blue lines which were originally the leaves forming the block. To make the Krayne mosaic screen these lined screens are again cemented together to form a block, and a section is now cut at right-angles to the line direction."

Mr. John W. Powrie in his color-screen has also discarded ruling methods. He takes advantage of the well-known hardening and protective property of bichromate of potassium when exposed to light, to stain a coated glass plate in lines of red, green, and blue, one color after another. These lines are only 1/600 of an inch in thickness, and more than twice as fine as those that can be obtained by ruling-machines.

But the popularity of these geometrically made color-screens (they are made in hexagonal and square patches, as well as in lines) has been somewhat impaired by the appearance of the "random grain" plates recently invented by Messrs. Auguste and Louis Lumière, of Lyons, France. It is true that this idea is of somewhat earlier origin, for in the last decade of the nineteenth century, J. W. McDonough prepared plates by scattering small flakes of colored shellac over the surface and then fusing them, but he soon abandoned this line of experiment for what he considered the greater advantage of the ruled screen. The Lumière "autochrome" plate is made by placing on the glass a layer of minute grains of potato-starch colored red-orange, green, and violet, so thoroughly mixed that they present a neutral gray to the eye. The grains are so small that five and a half million will go on a square inch of surface, and any spaces between them through which white light might filter are filled up with a black carbon powder. This layer is rolled and pressed on the glass, to which an adhesive coating has previously been applied. The layer of colored grains then receives a coating of waterproof varnish and on this is spread a gelatine-bromide emulsion sensitive to all colors. Thus we have a complete outfit—photographic plate and color screen in one. In exposing this plate in the camera the glass side is placed towards the lens, and the light consequently has to pass through the granular colored layer before reaching the gelatine film. The resulting negative is developed but not fixed, and the reduced silver is dissolved by means of the acid permanganate of potassium process. The plate is then transformed from a negative to a positive, and each colored particle lets the light pass which is necessary to produce that special shade. When held up to the light the plate shows the color as well as the shape of the photographic subject.

The ease of manipulation and excellent results of the Lumière autochrome plates have turned inventive effort largely to the methods used in their manufacture. Already a new plate known as the "omnicolor" has been produced. This, however, goes back to the old idea of the geometrical plate and is prepared by "treating a gelatine film (upon a glass plate) successively with certain reserves, coloring matters, and varnishes, thus producing a kind of mosaic of red and green rectangles, and blue lines. The red and green fields are quite regular in form; the blue lines, on the other hand, show constrictions at constant intervals, corresponding to their intersections with the red fields. As a matter of fact this red color is distributed in narrow red bands, and the blue lines superposed upon these produce at the point of contact a purplish violet color." These plates are used precisely as the autochromes, although the colors differ appreciably. "the green tending more toward yellow and the blue being less violet."

The great drawback to the autochrome plate is the loss of light. This defect is necessarily present wherever a color screen of any description is used, but the sensitiveness of the autochrome plate is comparatively small owing to the imperfectly transparent nature of the starch grains as well as the black filling-in material of the unavoidable interstices. Therefore, the physicist is still laboring to obtain increased brilliancy and brightness in the picture.

With this end in view Mr. Jan Szczepanik, by taking advantage of the property possessed by certain substances of absorbing coloring matter from others, has recently produced a plate that possibly may show the way to a considerable advance in indirect color photography.

"Szczepanik prepares three solutions of gelatine or gum-arabic. Each solution is colored with a suitable dye, and is then evaporated to dryness. The particular dyes used must, of course, have a preference for collodion. The solid masses of gelatine or gum-arabic obtained by evaporating the solutions are finely powdered, and the three powders of different colors are carefully mixed. The mixture of these colored powders is then sifted over a slightly moist collodion plate by means of a special apparatus. The coloring matters migrate from the gelatine powder into the collodion film, producing a mosaic of small colored patches similar to the starch granules of the autochrome plate. The powder originally dusted on the plate, which has lost its color, is washed off."

Results in color photography have also been obtained by the use of prisms or diffraction gratings instead of dyes or pigments. Professor Lippmann, of Paris, whose direct "interference" process we noted above, has devised a method employing the minute spectra of prisms. The apparatus employed is similar to the photographic spectroscope, except that "the single slit of the spectroscope is replaced by a series of slits very close together consisting of fine transparent lines ruled five to the millimeter. This grating is fixed at one end of a solidly built box, the other end carrying the photographic plate, and between these is a converging lens, in front of which is a prism of very small angle. The object to be reproduced is projected on the grating, illuminated with white light. The light passing through the prism and lens falls on the sensitive plate, producing a negative in black and white which under the lens appears lined, each line divided into small zones, which are parts of an elementary spectrum. If the negative be now replaced in its original position and illuminated by white light, the image of the object photographed is seen in colors which are complementary to those of the object; the latter appears in its own proper colors when the negative is replaced by a positive."

It will be seen that the apparatus in which the exposure was made must also be used to get a color image of the photographed subject. M. André Chéron, of Paris, has more recently improved the process to some extent, but nevertheless, like all of its type, it does not lend itself to practical work, and will always remain of more use and interest to the physicist than to the photographer.

THE FUTURE OF COLOR PHOTOGRAPHY

We have seen that the screen-plate, and especially that form developed along the line which has produced the autochrome and kindred plates, has thus far given the most satisfactory results in color photography. Nevertheless, the practicality of these methods is not very pronounced, and the popular attitude toward them was ably expressed by Doctor Mees in his recent address before the London Society of Arts.

"With regard to the whole use of screen-plates, one is bound to feel that, interesting as they are, at the present time their use must be limited. No color process which cannot be printed on paper can hope to appeal to the great mass of workers. . . . What screen-plates need, in fact, as their complement, is a printing-process such as some improved bleaching-out emulsion, which could be placed on paper and on which the plates could be printed."

In these words the future of color photography is clearly outlined, and before dismissing the subject it remains to note what is being done in this direction.

"There is a method," says Chapman Jones, "that has been in the minds of those interested in these matters for nearly thirty years, and latterly more or less worked upon by many investigators with more or less, but on the whole gradually growing, success. The three necessary colors are put on the paper to begin with, and the light destroys or bleaches those that are not wanted. The method depends upon the fact that light can affect a substance only when it is absorbed, and therefore when a mixture of unstable colored substances is exposed to colored light, there is always a tendency for those substances that are of the same color as the light to survive the longest because they reflect more of the light than the others." In 1907, such a paper ready for exposure under the color plate was actually prepared. "The colors are made more sensitive by the addition of anethole, and after exposure the print is soaked in benzine or acetone to remove the sensitizer. This paper gives surprisingly vivid reproductions of the color of the original, but the prints are not very stable to light."

When some means of making stable prints on such a paper is found, color photography will probably have reached its highest state of development, for, as we have seen, the photography of color is something the scientist as yet sees no possible way of accomplishing.

CHRONO-PHOTOGRAPHY—MOVING PICTURES

A means of representing motion, which has reached its highest development in the well-known and popular moving-picture machines of the present day, was devised long before the photographic plate came into general use. As early as 1833, M. Plateau, a Belgian scientist, invented an instrument which he termed the phenakistoscope, and by which he demonstrated the principle of the persistence of vision; that is, the retention of an illuminated image in the retina after such illumination has been quenched. From this instrument was subsequently developed the zoëtrope or "wheel of life"—a toy which many readers will doubtless remember. It consisted of a hollow cylinder revolving on a pivot and having a band of short, perpendicular slits, close together, perforated in its circumference. If a strip of pictures of the same object in different positions were placed around the inner surface of the cylinder, and the instrument rapidly revolved, the effect of the series of pictures, passing in succession in front of an eye placed on a line with the row of slits, was that of the pictured objects performing some sort of motion, as a horse running, a bird flying, or a human being dancing.

No further interest seems to have been taken in the matter until after 1870 when a Frenchman, Raynaud by name, modified and improved the zoëtrope by reflecting the succession of images in a many-sided mirror placed within the cylinder. This instrument, which Raynaud called the praxinoscope, gave precisely the same effect as the zoëtrope. It must be understood that the pictures used in these toy instruments were not photographs but a series of colored reproductions of drawings, and consequently, while this whole matter does not come under the head of chrono- or animated photography proper, some account of it in the history of the pictorial representation of motion is necessary.

In the 70's or 80's of the last century three scientists, Edward Muybridge in America, Stephen Marey in France, and Anschütz in Germany, although pursuing an entirely different subject, took the first steps in the development of chrono-photography. These men were deeply engrossed in the study of animal locomotion, and Muybridge's hobby was the horse. In 1877 he placed a series of cameras at regular intervals opposite an inclined white reflecting surface. A fine thread was stretched from the shutter of each camera and in front of the row a horse was caused to pass. The animal naturally broke the threads in turn, and as these acts operated the shutters, the investigator obtained a series of plates showing the horse's attitude at the moment of exposure. To combine these plates and obtain a moving picture Muybridge devised an apparatus which he termed the zoopraxiscope, by which the positives, arranged on an immense revolving disk, were brought one after another in rapid succession into the light of a projecting lantern.

Marey took up the principle of the "photographic revolver" which Jansen had invented in 1874 and adapted it to the analyses of very rapid movement. By means of the photographic gun he obtained excellent and valuable photographs of birds in full flight. Mention should also be made here of the work of George Demeny, a pupil of Marey's, who devised the photoscope for reproducing the motion of a man's lips so that deaf mutes could read "photographed sentences."

Anschütz's contribution to chrono-photography was the tachyscope (1887). His sensitive plate was a large glass disk on the periphery of which positives were made. The disk was fitted with contact pins and was rotated behind a slight opening, each picture, when it came behind the opening, being illuminated by a spark from a vacuum tube.

Such, in brief, is the story of the development of animated photography up to the time when a very important invention revolutionized this, as well as every other, branch of photographic art. As the reader may have guessed, the flexible celluloid film, substitute for the glass plate, is referred to. Marey now employed a long roll of sensitive film fed behind, and in the focus of, a photographic lens, and the same contrivance was quickly adopted by Thomas A. Edison in his kinetoscope. Edison is said to have conceived the idea of the kinetoscope as early as 1887. He at first proposed fixing the series of impressions on the outer rim of a disk as in the case of the tachyscope, but the tremendous advantage of the flexible film caused him to abandon his first principle. The kinetoscope, patented in 1891, was quickly followed by many other similar moving-picture machines with which the public is familiar under various names—vitascope, vitagraph, biograph, phantoscope, kinematograph, etc. The last-named appeared in 1895, and since that time no radical improvement has been made in moving-picture machines, although their use and popularity have enormously increased.

The method of making moving pictures is comparatively simple in principle, although in matters of adjustment and other practical details the greatest care and nicety must be used. At a high speed the film is fed rapidly behind the camera lens, the shutter of which is operated by a small motor. The speed of the shutter is such that from 900 to 1,800 separate pictures must be taken every minute, or from fifteen to thirty a second. Thus when any scene—a procession or a dramatic performance—progresses in front of the camera, a record will be obtained of the relative position of objects in the camera field, say every one-fifteenth of a second.

The films used are either $1\frac{3}{8}$ or $2\frac{3}{4}$ inches in width, and their length about fifty-five feet. Of course in many instances a number of films have to be used to reproduce a scene. Thus in the animated representation of a recent pugilistic encounter, which the whole world was believed to be passionately longing to view, the camera was operated steadily for one hour and forty minutes, and in this time between six and seven miles of celluloid film passed behind the winking lens.

To reproduce the pictures, a positive strip is printed directly from the developed negative, and this is passed through the kinematograph, biograph, or other moving-picture machine in the same manner as the original film is fed into the camera—a rapid shutter exposing the consecutive positions of the scene at the same intervals as were used in photographing the original.

The question will naturally be asked: What makes the picture "move"? And in answering this it must be first explained that the human eye is an absolutely essential part of any chrono-photographic apparatus. Let us take, for instance, the case of the kinematograph and consider what happens. In this particular moving-picture machine photographs are taken at intervals of one-fifteenth of a second.

Owing to the property of the retina, called "persistence of vision," to which we have referred above, a luminous impression cannot be instantly removed but will persist, and hence affect the optic nerve, for 2/45 of a second, and be further prolonged, though gradually weakening, for 2/45 of a second longer, after the illuminated object has suddenly disappeared. Now the moving pictures have been taken at 1/15 or 3/45 second intervals, and the various pictures are exactly alike in so far as the stationary part of the scene is concerned. A picture (let us call it image No. 1) is thrown on the screen and the opaque screen or shutter of the machine then masks the light for 1/45 of a second. Therefore, owing to the persistence of the image, we shall see the picture not only during the 1/45 second of eclipse but also 1/45 second afterward. But during the time of eclipse the next picture in the film (No. 2) has been substituted for No. 1, and consequently when the light is again unmasked after the 1/45 second interval we shall see not only the image No. 1, somewhat weaker, though still distinct, and superposed on it is image No. 2. Since the stationary parts coincide exactly, the eye perceives the sensation of the moving object, the attitudes and positions in No. 1 being succeeded by those of No. 2, and so until nine hundred such impressions are made on the retina every minute.

There is another method of presenting moving pictures, in use in the familiar slot-machine, or mutoscope, as it is called. Instead of the continuous film, the pictures are arranged in reels and brought into a vertical position before the eye. The reel is made up of several hundred photographs in consecutive order, and between each one is placed a piece of thin, calendered cardboard such as playing-cards are made from. These act in the manner of a spring to throw the photographs one after the other rapidly past the viewing lens. The insertion of the coin starts the motor which operates the reel.

Moving picture presentations are of two classes, the first, in which pageants, processions, races, or any other progressive events, are reproduced; and in the second, dramatic performances are depicted. In the latter, some startling and almost miraculous happenings are usually introduced, to the admiration and delighted applause of the spectators. These effects are accomplished by what is known as the "pause," that is, the camera is run up to a certain point, stopped, the mise-en-scène changed, and the picture-taking continued. Thus in the familiar "automobile accident," the camera is operated until the automobile is right upon the prostrate victim. Then a legless cripple, made up like the original model, and some artificial legs, are placed in the scene and the action continues. The legless man is then shown moving the dismembered limbs in the air. Now the legs are seen to fly back to the trunk, and at length the original model walks away, none the worse for his experience. These different phases of the thrilling episode take much time and trouble to prepare, during which time the camera is "in pause"; but when thrown on the screen in the moving-picture theatre the whole thing is over in the fraction of a minute.

THE USES OF PHOTOGRAPHY

It is safe to say that to-day there is no field of scientific research, or the practical conduct of affairs, to which photography has not become an indispensable adjunct.

Of the immeasurable realms of space, as well as the minute, invisible world about us, the photographic plate has given knowledge that never could have been obtained by the human eye alone. It has unfolded the wonderful world of the spiral nebulæ and laid the groundwork for modern conceptions of the universe. It has shed light on the nature of the streaky nebulæ and their connection with the great star-stream of the Milky Way, into whose depths it has given us the only means of penetration. It has shown the existence of countless stars, as well as faint members of the solar system, which the human eye aided by the telescope lens has been unable to perceive. It has given much additional insight into the conditions and development of the sun's constituents, and enabled us to measure the motion of the stars toward and away from our own solar system.

It would be impossible to give any account of the recent triumphs of physical and chemical research without allotting considerable space to the part the camera has played in them. The fact that the sun and fixed stars contain the same elements as does the earth is imperishably recorded by spectrum photography. All knowledge revealed by the ultra-violet rays of the spectrum has been acquired by use of the photographic plate, since the extremely short length of the waves renders them invisible to the human eye.

The value and use in medicine and surgery of photographs taken with the Röntgen ray, have already been described. More recently the kinematograph has been adopted in the study of diseases, especially those of nervous origin. By its means faithful records of the abnormal play of features, convulsive movements, strange attitudes, faulty gait, etc., may be obtained, the careful observation and study of which when thrown on the screen has proved of invaluable aid and service to the physician. The mystery of the background of the eye was finally solved by stereo-photography. The use of microphotography in obtaining records of minute organisms and their development is only another of the many ways in which photography has become indispensable to the pathologist.

In zoology and botany the camera has revolutionized all methods of observation and research. The photography of animals and plants in their natural environment is a most valuable means of investigation and information and not of mere illustration, as some may suppose. For these same purposes the kinematograph is being put more and more to practical use by the zoologist. Microphotography is rarely absent from the work of the botanist, and from it results of enormous practical and economic value have been obtained in the department of plant pathology.

In architecture, surveying, and map-making, the camera has been put to much practical use. It is fast replacing—especially in mountainous countries—the plane-table as a means of obtaining accurate topographical maps. Architectural measurements are obtained with great exactness from photographs.

Into the conduct of law, photography now enters in large part. Its applications are too numerous to be mentioned here in detail, but its possibilities as a means of information will be evident to anyone who thinks a moment on the subject. The establishment of identifications—one of the most difficult matters in criminal procedure; the detection of forgeries by photographic enlargements; the accumulation of indisputable descriptive evidence in all kinds of accidents; the preservation of the exact conditions surrounding the commission of crime, which may afterwards be changed, such as the appearance of wounds, the location of hand and foot prints; the relative position of furniture, etc.; the collection and dissemination of criminals' portraits—these are but a few of the ways in which photography is employed by every well-policed nation. Truly may it be said that in every department of human activity "the sun brings all things to light."

XI

PAINTS, DYES, AND VARNISHES

ANY liquid substance that is applied to the surface of a solid, either as a protective or for decorative purposes, may be regarded as a "paint," generally speaking. But when used in this way the word is far too comprehensive. Subdivision and classification of the substances used for coloring is necessary for intelligent understanding of the subject. Fortunately the substances all fall naturally into three or four definite groups, determined either by their use or by their chemical nature, although the dividing line is not clearly drawn in some instances.

For practical purposes the substances generally known as pigments may be considered either as paints, varnishes, stains, or dyes. The last two are identical in many instances, the substance upon which their application is made, and the method of applying them, determining whether they shall be called "stains" or "dyes." Thus we speak of "staining" a piece of wood, and of "dyeing" a cotton or wool fabric, although the pigment used in each instance may be the same.

Generally speaking, dyes, stains, and varnishes are transparent or translucent substances in solution, or chemical combination, with a liquid; while paints are opaque, insoluble substances, held in suspension in some medium. Thus a stain or dye enters into intimate combination with the wood or the fabric to which it is applied. Being transparent it does not conceal the grain of the wood or the fibers of the cloth that it colors, and does not increase its thickness to any appreciable depth. A paint, on the other hand, simply covers and conceals the underlying structure by an appreciable layer without becoming an integral part of it. This is shown in the familiar example of paint peeling off wood, leaving the original surface exposed.

A varnish is essentially a transparent paint, rather than a stain. Color effects may be produced very much the same as in the case of stains by incorporating a transparent pigment in the varnish; but it is possible for a varnish to peel off from an underlying surface, just as in the case of a paint.

In speaking of the various paints their "covering power" will often be referred to. This should be understood as meaning the amount of surface that a pigment will conceal with an opaque layer. This quality is often determined by the size of the individual particles of the opaque pigment, the smaller the particles the greater the covering power, generally speaking,—a rule, however, that is subject to many exceptions.

The processes in paint manufacture known as "grinding," "filtering," "precipitating," etc., are sufficiently self-explanatory without going into details here. What is known as "levigation," however, needs fuller explanation.

The principle of the process of levigation depends upon the fact that the larger particles of a substance, or heavier particles when mixed with lighter ones, tend to settle first to the bottom when the substance is agitated in water and then allowed to stand. In practice there are various methods of applying this principle. A very common one, in use where the raw material is composed of a mixture of several different-sized particles, is to arrange currents of water and settling-tanks so as to separate these particles into deposits of great uniformity. In an arrangement of a series of tanks through which the liquid flows, the first tank will arrest and collect the coarser particles; the second tank will arrest the particles that are somewhat finer; the third will arrest still finer particles, and so on until the last tank receives only the very finest particles. This may be taken as a typical method of levigation. And without entering into details it may be said at once that this process is perhaps the most important single one connected with mineral-pigment manufacture.

Reducing the pigment to a fine powder by grinding is as old as recorded civilization itself. The kinds of mills used for grinding do not differ, except in details, from those used at various times for grinding other materials, such as grain. Indeed, the mortar and pestle, quern or hand-mill, millstones of various kinds, and, finally, roller-mills, have been applied to color-grinding in the order of their development, just as in the case of grinding grain.

Only second in importance to the pigments themselves —if, indeed, their place may be considered secondary —are the vehicles in which they are incorporated for use in painting. Water is, of course, an important vehicle. But much more important are the "drying-oils." Of these drying-oils linseed oil is of most importance to the painter—more important, in fact, than all the other vehicles combined.

By a "drying-oil" we mean one that, when exposed to the atmosphere, forms a thin, tough film, insoluble in water, and not acted upon readily by any chemicals that are likely to come in contact with it. The number of such oils is very small in comparison with the number of oily substances, of which olive oil may be taken as a typical example of a non-drying oil. A thin film of this oil spread upon a surface of glass, let us say, does not tend to form a hard film and lose its peculiar oily quality, even after weeks of exposure to the atmosphere; whereas under similar conditions a film of linseed oil would be converted into a hard, impervious layer, in a matter of twenty-four hours. Olive oil, therefore, and all the other non-drying oils, are useless as paint vehicles.

For special purposes several other drying-substances besides the oils are used for pigment vehicles, among the most used of these being turpentine, benzoline, shale spirits, benzole, coal-tar naphtha, wood alcohol, alcohol, and water. But all of these must be regarded as strictly of secondary importance to the drying-oils, although for special purposes they are indispensable.

Of the drying-oils there are, besides linseed oil, poppy-seed oil, firseed oil, weld-seed oil, hempseed oil, tobacco-seed oil, menhaden oil, walnut oil, and Chinese wood oil. But all these together play a very insignificant part as paint vehicles in comparison with linseed oil, which can be produced in great quantities and at a cost that is a mere fraction of that of any of the others.

Linseed oil is the product of the seed of the flax plant, *Linum usitatissimum*, which is grown abundantly in every grain-raising region of the world outside the tropics. It is a little seed, flat oval in shape, lustrous, and of a pale-brown color. The oil is obtained from the seed by a process of pressing, after the seed has been subjected to a series of preparatory processes.

As a vehicle for pigments it is marketed in two forms, known respectively as "raw" and "boiled" oil. The raw linseed oil is the product obtained from the seed by pressure, without further treatment—or at most a process of clarifying and refining—and represents the oil practically in a state of nature as it exists in the seed. The boiled oil, as the name suggests, is the natural oil which has been heated above the boiling point (about 500° F.) and to which is added a small quantity of some substance known as a "drier." The boiling and the addition of the drier change the chemical composition of the oil slightly, and give it somewhat different properties from the raw oil—mostly in the matter of increasing its rapidity in drying. For this reason it is a favorite vehicle for many kinds of painting where a hard, tough, lustrous coat that dries quickly, is desired. This coat is somewhat more prone to crack than the one formed by raw linseed oil, but this tendency may be corrected by adding a little raw oil to the mixture, the compound forming the ideal vehicle for most commercial painting.

The quantity of drier added to the boiling oil is very small, usually four or five pounds to the ton of oil.

Larger quantities of driers impair the lasting qualities of a paint, and should not be used except in places where the rapid drying of a layer of paint is of more importance than its durability.

Some vehicles, such as turpentine, act as rapid driers, but are not considered as "driers" in the generally accepted commercial use of the term, which applies to such substances as red lead, monoxide of lead, the acetate or borate of lead, one of the manganese salts, or one of several zinc or iron salts. These may be used separately or in various combinations, and are the basis of the numerous "patent driers" on the market, the indiscriminate use of which has brought such substances into disrepute.

While linseed oil is a relatively cheap substance as compared with other drying and non-drying vegetable oils, its cost is sufficient to lead to much adulteration and to stimulate the search for cheaper substitutes. None of these substitutes equals linseed oil, however, although some mixtures of boiled oil, resin oil, and resin or turpentine, are fairly good vehicles.

Hempseed oil, while scarcely attaining the position of a rival of linseed oil as a vehicle, is used extensively in Russia where hemp is grown on a large scale. In that country hempseed and linseed are usually mixed together, so that the expressed oil is a mixture of linseed and hempseed oil. As hempseed oil seems to possess all the good qualities of linseed oil, the mixture is a high-class paint-vehicle. In this country the cost of hempseed oil for commercial painting is prohibitive.

Poppy-seed oil has the advantage over linseed oil of being almost colorless. For this reason it is a favorite with artists; but it is far too expensive for use in commercial paints. This is true also of walnut oil and tung, or Chinese wood oil.

Turpentine, which is a product of the distillation of the resin of pine trees, is a most useful paint-vehicle for certain purposes. It volatilizes rapidly on exposure in thin layers to the air, but leaves behind a thin layer of resinous substance that acts as a binding medium for the particles of pigment. It mixes with alcohol, ether, and benzine, and is a good solvent of fats, oils, and resins, so that it can be used with almost every kind of paint or varnish. It dries very quickly, and for quick-drying paints, stains, and varnishes is indispensable to the painter.

The best substitute for turpentine, although inferior as a paint-vehicle, is resin spirit, the product of the distillation of resin. In its most refined forms it can be used as a substitute for turpentine for every purpose; but it has a very offensive odor, and its use is largely confined to making cheap varnishes.

The two alcohols, methyl alcohol and ethyl alcohol, are used extensively as vehicles in the manufacture of varnishes and enamel paints. They are good solvents of gums and certain resins. They evaporate rapidly and as vehicles for pigments constitute quick-drying "paints." The most familiar example of one of these is the ordinary commercial shellac varnish.

Besides the vehicles we have mentioned there are, of course, scores of others, either "patent" or "proprietary" mixtures, which are constantly appearing on the market. Most of them are mixtures, but their exact compositions are trade secrets, and need not be considered here.

THE PIGMENTS OF ANTIQUITY

"When Noah built the ark," says a writer, "and coated the seams with pitch, he was doubtless following the most approved system in use of protective coatings on structural materials, which was then probably of remote antiquity and traditional origin, and which he may have learned when he was a boy four or five hundred years before."

It appears, then, that the use of some sort of protective in the form of paint or varnish dates back to a very remote period of antiquity, not necessarily on the statement of the Mosaic writers alone, but from existing evidences that antedate them by many centuries. It is interesting, however, that one of the earliest written accounts of boat-building shows that the workmen coated their boats with the same material that is still used for similar purposes the world over. Since it is unlikely that this ideal material should have been hit upon from the very first, it is evident that the use of protectives had passed through a long experimental stage at the very dawn of written history. But even if no word had ever been written about this, we still have the mute evidences in the form of remains from ancient dwellers of the Nile and the Euphrates, showing that paints, varnishes, and dyes were used extensively by them for ornament and decoration as well as for protectives.

We shall see a little later that within the last half-century a complete revolution in the method of making certain colors has taken place, thanks to the science of chemistry. Yet the basis of most paints is still the time-honored white lead—a substance known to the ancients, and used by them practically as it is used to-day. We know that as early as the fourth century B.C., there were written accounts of the process of making this substance, which seemingly differed very little from the process in use in some countries to-day.

Varnishes seem to have been used at a date almost, if not quite, as early as that of paints. The peculiar coatings of the Egyptian mummy-cases has been analyzed and found to be a solution of resin in an essential oil, such as turpentine or oil of cedar, and therefore practically identical with the ordinary varnishes of to-day. The revolution in the art of paint- and pigment-making, therefore, lies outside the field of the exact knowledge of the chemical nature of such basic substances as resin, pitch, and white lead. There have been revolutionary changes in the methods of obtaining and using these substances, of course, but the great revolution has come in the manufacture of the colored pigments along the lines of synthetic chemistry. The ancient pigment-maker was largely dependent upon the substances furnished him by Nature in a form ready for use. Many of these were rare, costly, and difficult to manipulate. His modern successor, with his knowledge of chemical elements and reactions, produces the same material in his laboratory, at a mere fraction of their former cost, and from substances that would never have been dreamed of in earlier times. An example of this is the manufacture of ultramarine. The early painters made this substance by grinding to powder the gem "lapis lazuli," and the pigment so produced was worth many times its weight in gold. The pigment-maker of to-day produces a deeper and better color by a chemical process in which sulphur, soda, silica, and clay are the important factors, and makes a handsome profit if his product brings him fifty cents per pound. This is but one example of how a product of man's puny laboratories has supplanted that of Nature's great one. We shall see presently how many such examples there are in this particular field.

BLACK PIGMENTS

The element carbon, in one or another of its varied forms, is the basis of practically all black pigments. It is one of the most universal elements, and being found in abundance in the mineral, vegetable, and animal worlds, pigments are made of it from all three of these sources. Although all forms of carbon, such as diamond, coal, charcoal, and lampblack, are identical chemically, it is obvious that only certain of these forms are available for making black pigments. Thus diamond dust is white and coal dust black; yet both are pure carbon. The chemist would explain, however, that both their substances are crystalline, and that only the non-crystalline forms of carbon give the desired pure-black color. Of much greater importance to the pigment-maker are such plebeian substances as wood, charcoal, bones, and smoky lamps charged with foul-smelling oils, as it is from these sources that he makes his wares.

As most of the forms of carbon found in the mineral world, except the mineral oils, are crystalline in character and hence not available for making the best pigments, the vegetable kingdom furnishes the cheapest sources. For production from the latter two general methods are used; one, the process of dry distillation, or heating the substance to be carbonized in the absence of air; in the other the supply of air is restricted. An example of the last method is shown in the soot formed by smoky lamps or defective gas-burners, such soot making the finest forms of black pigment which may be used without further treatment. In the case of the carbon produced by dry distillation, a good pigment can be produced only by grinding and the addition of oil.

In the commercial world there are two principal kinds of black pigments, "charcoal" blacks and "soot" blacks. Practically all black pigments on the market, regardless of their commercial or trade names, have one or the other of these two blacks in them. It is possible, of course, to make a fine black from such a substance as ivory; and "ivory black" was formerly made exclusively from this substance. But aside from some of the very finest forms of artists' pigments, little ivory black is now made from ivory, the name indicating the quality rather than the composition of the pigment.

In making charcoal black the first step in the process, that of making the charcoal, does not differ materially from that of the ordinary process of charcoal-burning.

There is a difference in the selection of woods from which the charcoal is made, however, the soft woods making much better pigments than the hard. Spent tan-bark makes a good pigment charcoal, and is used extensively for this purpose in some places.

The usual method of burning the charcoal is to pile short pieces of wood on end into a stack resembling a cock of hay, some of these stacks containing several cords of wood. When completed, the stack is covered with a layer of clay or dirt, a certain number of openings being left for the admission of air. The wood is then lighted, and allowed to char by slow combustion, the rate of burning being regulated by the openings through the dirt covering. If combustion takes place too slowly the openings are made larger; on the other hand, they are reduced in size if sufficient air is being admitted to support a bright blaze.

To make such charcoal into practical pigment it must be reduced to a fine powder by grinding. It must then be washed thoroughly, either in water or a dilute acid, to remove all impurities.

A charcoal black, known as "vine black," is made from the lees and the pressed grapes used in the process of wine-making. In some of the wine-producing regions of Europe the industry of making charcoal for this vine black is quite an extensive one, and the pigment so produced is of very fine quality. The first step in the process of making this black is that of drying the lees at a moderate temperature. When the moisture has been removed the dried lees are placed in iron tubes (old stove-pipes, frequently) coated with clay, and surrounded completely except for a small vent for the escape of the gases in the subsequent heating-process. A very fine black pigment is made in practically the same manner from the remains of the pressed grapes.

A form of charcoal made by the dry distillation of bones is known as bone black, or, in its finer qualities, ivory black. To make this pigment the bones are reduced to small particles which are placed in closed crucibles and heated. As a result of this heating the inorganic portion of the bones is reduced to bone ash, while the organic portion is reduced to pure carbon and deposited on the inorganic particles. Thus the calcined substance contains only about twelve per cent. of carbon; but this is sufficient for making a very good black pigment when the mass is ground to a fine powder. If a very pure article, such as that used by painters and black-and-white artists, is wanted, the bone ash may be removed simply by treating the ordinary bone black with hydrochloric acid, which dissolves the bone ash, thus liberating the particles of a very pure and very finely powdered carbon.

It is rather curious that the soot from hard wood does not make good pigment, just as the charcoal from such wood does not. With this restriction, however, it may be said that good pigment may be made from any easily combustible substance that is rich in carbon, such as pine wood, resin, and the various animal and mineral oils.

From the fact that all black printing-inks, and most of the best black paints and lacquers, are made from soot black, it may be correctly inferred that the manufacture of this product constitutes an enormous industry. The apparatus for its manufacture consists essentially of a chamber in which the substance rich in carbon can be burned at the lowest possible temperature, and some arrangement for catching the carbon and separating it from the products of combustion. The primitive apparatus used in the pine regions, where the roots of pine trees are utilized for making soot black, is the same in principle as the more perfected apparatus developed from it. It consists of a low flue built of masonry, connected with which is a long wooden pipe. This pipe is lined with coarse cloth in order to give a rough surface upon which the soot is deposited. A brisk fire of dry wood is first started and kept up until the flue is thoroughly heated so that there will be little tendency for the soot to be deposited there and later consumed by accidental overheating. When the flue is thoroughly heated, pine roots and resinous chips are introduced and burned slowly, a dense, black smoke issuing from the tube as an indication of the state of combustion.

Keeping such an apparatus at the right working temperature requires much skill, experience, and vigilance, as the workman has nothing but his natural senses to guide him. If the fire is too active there is likely to be combustion in the tube, and a loss of soot black, whereas if it is allowed to get too low a very poor product is obtained. The condition of the flame is regulated by the admission or exclusion of air in the flue, the appearance of the flames indicating whether the amount of air is right or not. The ideal condition is difficult to describe. Generally speaking, however, the flame that produces the best soot is a long, dull, red one, with dark smoke issuing from the tip—much such a flame, indeed, as one sees in a smoky lamp. To keep this condition as nearly as possible, the workman opens and closes the "draughts" of the flue, these draughts consisting frequently of bricks which he piles before the opening or removes as the case requires.

It is hardly necessary to say that in such a primitive soot-gathering apparatus the maximum quantity of high-quality soot is seldom obtained. In its perfected successor, however, very little of the soot escapes. Yet the difference between the two is one of construction, not of principle. The better apparatus has the masonry flue supplied with necessary draughts with which the amount of air admitted can be regulated to a nicety. In place of the long wooden tube, a brick or cement tube is used, and this in turn connected with a high stack which is supplied with a damper. The pine root has been largely supplanted by resin for use in such furnaces, and a product of better quality and greater uniformity is obtained. However, even the very best product obtainable from pine or resin is not considered fine enough for the finer printing-inks, such as those used for making half-tone illustrations. These inks were made formerly from fatty oils or fish oils, this variety of soot black being known as "lampblack"; but in recent years mineral oils and tar oils have been found to be satisfactory substitutes. When vegetable oils or fish oils are used, however, the cheaper and more rancid they are, the larger is the yield of lampblack.

For using any of these oils special lamps are made, having different kinds of burners adapted to the various oils, some of them being very much like the ordinary kerosene lamp used for illumination. As a rule, however, a wickless burner of some kind is less expensive and preferable, such lamps being arranged so that they receive a continuous feed of oil, with an apparatus for regulating the supply of air, and a chamber for collecting the soot as it forms.

The soot so formed is not pure carbon, but contains varying quantities of the products of distillation. For ordinary purposes, however, these impurities are not sufficient in quantity to impair the quality of the pigment. But if a perfectly pure carbon is required, it may be obtained by boiling the lampblack with a solution of caustic soda, and then treating the residue with some acid.

A very simple apparatus for obtaining a continuous supply of fairly good soot is one in which the flame of the oil lamp is brought in contact with a revolving iron cylinder, fitted with a water-chamber for keeping it cool. As the flames come in contact with this cooled surface the soot is deposited in a continuous line, which is removed by brushes placed on the opposite side of the cylinder, or at some convenient point. The soot so gathered is received on an inclined plane, down which it slides into the receiving-box. Such an apparatus is simple and inexpensive, and by its continuous action produces an enormous quantity of soot in the course of the working-hours of a day.

The peculiar black pigment known as India ink is a mixture of soot, glue, camphor, and musk. The best varieties of this pigment are made in China, and the exact process of its manufacture is still a secret. It is quite possible that the quality of the product is due to the method of manipulating the ingredients rather than to the quality of the ingredients themselves. By some it is thought that the superiority lies in the material from which the soot is made, or that it is made from a substance not readily obtainable in the West. It has been suggested, for example, that the soot may be made from the wood of the camphor tree, and that this is peculiarly adapted for making this particular pigment; but it seems more reasonable to suppose that it is the method of making, rather than the material contained, that makes the Chinese ink superior to the European.

WHITE PIGMENTS

White lead is one of the oldest known pigments. The Romans manufactured it and used it in great quantities, and the name they gave it, *cerussa*, is still used in commerce. It is known also as flake white, Dutch white, Venetian white, Krems white, and by a score of other names.

Chemically, white lead is a basic lead carbonate—that is, a compound of lead carbonate and lead hydroxide; and commercially it is supposed to be this substance. In point of fact, however, it is found in the market adulterated with all manner of different substances. Indeed, there are probably few commercial products that lend themselves so temptingly to adulteration, and in which the manufacturer so frequently yields to the temptation. Not long ago the United States government investigated the product of a supposedly reputable firm which had been widely advertised as a "pure lead-and-oil paint." The investigation proved that there was not one grain of lead or one drop of linseed oil in the much-heralded paint. From this it will be correctly inferred that white lead is a relatively expensive substance to produce. This production is accomplished by many different processes, although all of them are governed by the same general principle of chemical action.

Briefly stated, this is the action of acetic acid upon metallic lead, producing a lead acetate, which is in turn acted upon by carbonic acid and changed to a lead carbonate.

The three most commonly practised methods of manufacture are known as the Dutch (or German, or Austrian) process; the French process; and the English process. In the Dutch process, metallic lead is used as a basis; in the French, lead acetate; while in the English, litharge (lead oxide) is used. When metallic lead is used the metal is cast into sheets or strips, as metal so treated is much more readily acted upon by the acid than if pressed or drawn.

The Dutch process is very old and very crude, but is still used extensively in some countries, and has the merit of making a good quality of white lead. In this process the vessels containing metallic lead and acetic acid are surrounded by manure, or by spent tan-bark, in a closed chamber. The heat generated by the fermentation of this material facilitates the action of the acetic acid upon the lead in forming the lead acetate. At the same time carbonic acid, which is given off in the process of fermentation, combines with the lead acetate to form white lead. It takes from four to six weeks for the process to be completed, but at the end of that time from eighty to ninety per cent. of the metallic lead will have been converted into white lead, which is washed and ground into the white powder of commerce.

Aside from the cost of the material in the manufacture of white lead for pigment there is constantly the danger of poisoning during the process. White lead is an insidious poison, and the colics and paralyses of lead-workers have been known for ages. It is advisable, therefore, for manufacturers to provide mechanical means of conducting the operations of manufacturing their product; and this is required by law in many countries.

The German or Austrian process of making the white lead is the same in principle as that of the Dutch, but in this method the heat and carbonic acid are produced by ordinary combustion. Specially constructed furnaces are made in which the products of combustion are made to pass over the solution of lead acetate; and as carbonic acid is one of these products, a combination of this substance with the lead forms the lead carbonate or white lead.

In the French process, the solution of the basic lead acetate is made from the metallic lead ribbons. Into this solution carbonic acid gas is passed, this gas being generated either by heating limestone, which produces a very pure gas, or by the combustion of coal. This process was invented by the chemist Thénard, and is used extensively in France.

For the English method, which is gradually dropping out of use, a stiff paste of litharge (PbO) is made by mixing it with a solution of lead acetate. This mass is kneaded by means of grooved rollers, through which carbonic acid is brought in contact with the paste. By this method a good quality of white lead was produced only when the litharge was perfectly pure lead oxide. But as commercial lead oxide is often contaminated with other oxides, such as copper and iron, white lead manufactured by this process is likely to be a mediocre product.

Despite the fact that white lead has held first place among the mineral pigments for so many centuries, not only as a pure white pigment but as the basic substance for forming other shades and colors, it is not, strictly speaking, a permanent white when used as a pigment. It is affected by sulphuretted hydrogen and the sulphides, and forms a black substance, lead sulphide, when brought into contact with them. As the atmosphere everywhere contains more or less sulphur, or sulphides, the air of some cities being strongly contaminated, the fate of every coating of white-lead pigment is eventually to turn gray, or even dead-black in time. This change is effected very gradually, of course—so gradually, indeed, that under ordinary circumstances the other causes for the wearing-out of the coat of paint will make it necessary to repaint a building before the white lead has turned to more than a very light gray. In such a smoky city as London this change will naturally be much more rapid than in the open country where the air is practically free from sulphides. In such places as the vicinity of sewers, where the percentage of sulphides in the air is very high, white-lead pigment turns gray very rapidly. Nevertheless, this defect in white lead is so completely offset by its good qualities, that it remains the most popular of pigments.

The one quality above all others that endears it to the practical house-painter is its remarkable "covering power"—the property of covering a great space with an opaque layer. But besides this, the lead paints are very durable, and may be used in an endless variety of combinations.

If the question of permanency of color were the only thing to be considered in selecting a white pigment, however, the zinc, bismuth, and barium compounds would have a better standing than white lead, as all of them are less affected by atmospheric changes. In fact, the only really permanent white familiar to the paint trade is the sulphate of barium, known popularly as "enamel white." This pigment will retain its pure whiteness indefinitely, even a long exposure to London smoke and fog having no effect upon it. Furthermore it can be produced for something less than half the cost of white lead. But when the relative covering powers and mixing qualities of the two are considered, practised painters regard white lead as the better pigment.

In proof of this we find the painter always seeking a pure white-lead paint, while the dishonest manufacturer is forever trying to foist upon him a white-lead paint adulterated with the cheaper sulphate of barium. And yet, if we may believe the results of the investigations of certain competent but disinterested persons, this prejudice against the barium pigment is, in part at least, a traditional one, not justified by facts. Such investigators claim to be able to prove by practical demonstration that enamel white is quite as good a pigment as white lead—even better, indeed—and that it is destined slowly but surely to replace the more costly and poisonous material. That it has not done so hitherto, they say, is because it is so difficult, even in this age of iconoclasm, to overthrow beliefs that have been accepted as facts for so many centuries.

Barium sulphate not only resists the action of the atmosphere, but is not affected under ordinary circumstances either by strong acids or alkalis. It is found in nature as the mineral barytes, or heavy spar, and is sometimes obtained in so pure a state that it may be ground to powder and used as a pigment without further treatment. When treated in this manner, however, it is not so good a pigment as the product of chemical combination, as the particles cannot be reduced to such a fine state of subdivision by the mechanical process of grinding as they are by chemical action.

When the enamel white is to be made from witherite, as the native barium carbonate is called, this substance is first dissolved in hydrochloric acid, and a solution of barium formed. Sulphuric acid is then added to the solution and in this manner the insoluble barium sulphate, or enamel white, is formed, and thrown down as an insoluble precipitate. The particles of the barium sulphate thus formed are so tenuous that they will pass through the finest filter—a state of subdivision that cannot be approached by any known process of grinding. As the finer particles make the better pigment, it is obvious that the enamel whites prepared artificially are better than those prepared from the natural product.

Another pigment that in many respects compares favorably with white lead, and which is only slightly less permanent than enamel white, is zinc oxide, known commercially as "zinc white." In point of cost it has a disadvantage, costing somewhat more than white lead. On the other hand, ten parts of zinc-white paint are said to have as great covering power as thirteen parts of white lead, so that the initial cost is practically offset by the results.

The zinc white of commerce comes on the market as a product from the zinc smelting-works, as it is formed when zinc vapor is burned in the air. It has the advantage over the lead pigments of mixing with pigments that contain sulphur without alteration. And since it is much lighter than the lead compounds, it is better adapted to mixing with the lighter vegetable pigments, such as the lakes.

The white pigments just described may be taken as the most important ones for commercial purposes. There are a few others, such as those made from antimony compounds, and from bismuth, tin, manganese, and magnesia, which are of practical value for certain special purposes, but even in the aggregate these are relatively unimportant as compared with the lead and zinc compounds.

PAINTS, DYES, AND VARNISHES

SOME "CHROME" PIGMENTS

For making the yellow pigments—or more specifically, the chrome-yellow pigments—the compounds of the same three important metals, lead, barium, and zinc, are also the most important. Here again the product of the lead salts is the one most sought by the practical painter, although it is a very poisonous pigment, and, as the chemist points out, lacks the permanency of the other two. It has one cardinal point in its favor, conceded by both chemist and artisan: it is a more brilliant and beautiful yellow at first than any of the compounds of the other metals. But this brilliant color is not permanent, and when exposed for a long time changes to a dull color much inferior to the yellows of either zinc or barium. Nevertheless lead chrome yellow is the most popular of the yellow pigments to-day for general commercial purposes.

Nature furnishes a lead chromate in the rare mineral, crocoisite, found in some lead mines; but the chrome yellow used for pigment-making is an artificial product. It is made by mixing a solution of potassium chromate, or bichromate, with a solution of some lead salt, frequently the acetate of lead. Curiously enough, the exact shade of color of the product depends to a very considerable degree upon the relative amounts and strengths of the two solutions used. In the ordinary chemical reaction the molecules of the resulting compounds will be the same, whatever the relative proportions of the basic solutions; but in the production of lead chrome yellow the exact shade can be determined by the amount of the two liquids used. By understanding this it is possible for the manufacturer to produce a lighter or darker shade at will. To produce the numerous shades of yellow that cannot be made directly by the initial process, varying quantities of white lead are used. These may be added after the process of precipitating the chrome lead is completed, or may be precipitated at the same time. The white-lead salts add greatly to the brilliancy of the pigment.

In some instances there is a chemical combination between the lead chromate and such a salt as the sulphate, so that the resulting light-yellow compound is not merely a mechanical mixture of two lead salts, but is a chemical compound.

When the manufacturer wishes to produce one of these pale shades of yellow he adds a certain quantity of sulphuric acid to the solution of the chromate used, and mixes this with the acetate-of-lead solution. In the reaction that follows a certain quantity of the white sulphate of lead is formed with the lead chromate, and is precipitated with it, either as a chemical combination, as we have just said, or as a mechanical mixture having a perfectly uniform color. The shade of color so produced will vary with the amount of sulphuric acid used, larger quantities of the acid making corresponding lighter shades of yellow. The process of making zinc chrome yellow, and barium chrome yellow, is very much the same as for making the lead chrome yellow.

Nature furnishes another lead pigment in the form of lead monoxide (PbO) which, in its crystalline form, is called litharge, and in its amorphous form, massicot. The crystalline salt is a dull yellow, while the amorphous one is a reddish yellow. These substances are not used very generally as pigments, although there is another lead oxide, in which the molecule contains lead and oxygen in the proportion of three to four (Pb_3O_4), which is the bright-red pigment used by plumbers as a cement for pipes.

A yellow which is distinctly inferior in quality to the chromic-acid salts of lead, zinc, or barium, is calcium chrome yellow. It is a very permanent color, however, and is much cheaper than the other three, so that it is popular in places where price and permanency, rather than beauty, are the principal conditions.

"Turner's yellow," which was invented by James Turner late in the eighteenth century, and was popular for many years, is a pigment that has been superseded in later years by the chrome and ochre pigments which will be presently described. It was an oxychloride of lead, made from litharge and ammonium chloride, and was known under the various names, Montpelier yellow, Cassel yellow, Kassler yellow, Verona yellow, and probably others.

"Naples yellow," a compound of the oxides of antimony and lead, which was a popular pigment at one time, has also been replaced by the chromes, over which it has no advantage.

A beautiful and permanent chrome yellow is made from the metal cadmium, but this pigment is too expensive for ordinary commercial purposes. It is sometimes used as an artist's pigment, but more generally the cadmium yellow, which is made by the action of sulphuric acid upon the metal, is preferred.

Mars yellow, which is quite a favorite with artists, is a mixture of oxide of iron with calcium or aluminum sulphate, while aureolin is a double nitrate of potassium and cobalt. There are also yellows made from arsenic, mercury, antimony, and thallium that are sometimes used for pigments; but none of these has any great value commercially as compared with the chrome yellows enumerated.

The familiar yellow seen in the gilding of picture-frames, which rivals gold in luster, is a bisulphide of tin (SnS_2). It is known as "mosaic gold," and is made by heating together tin filings, sulphur, and ammonium chloride, the relative proportions being varied considerably by different manufacturers. In the heating-process care must be taken not to raise the temperature too high. It is to prevent this that the ammonium chloride is used. This salt volatilizes at a relatively low temperature, and so long as this volatilization is going on, the general temperature of the mass containing it will not be raised high enough to injure the product. By this process a pigment may be made, the luster of which closely rivals the pure metal it is made to imitate.

A cheaper and inferior mosaic gold can be made by a wet process, in which the bisulphide of tin is precipitated from the solution of a tin salt by the action of sulphuretted hydrogen. When prepared in this way, however, the pigment not only lacks luster, but is of a distinctly inferior color.

OTHER YELLOW MINERAL PIGMENTS

The principal yellow mineral pigments are the chromes and ochres, although there is a long list of yellows and oranges from other sources that are occasionally used. The base of all the chrome pigments is the chromate of lead (PbCrO) and its basic modifications. The lead chromates are readily obtained by mixing a solution of potassium bichromate with a solution of lead acetate, and vary in color from light yellow to deep red. As placed on the market commercially, the darker shades are likely to be pure lead chromates; while the lighter shades represent a mixture of the darker base with some white pigment, such as sulphate of lead, or enamel white. These mixtures do not necessarily impair the quality of the pigment. Indeed the "pure chromes" of commerce are really mixtures with the lead sulphate. Thus "pure" lemon yellow is made from the following formula:

Lead acetate (or nitrate)	100 parts
Bichromate of potash	25 "
Sodium sulphate	35 "

If this formula is varied a little, such as by increasing the amount of bichromate of potash five parts, and the sodium sulphate diminished fourteen parts, "pure" chrome yellow is formed. And if the sodium sulphate is omitted entirely, "deep" chrome yellow is made. Still other shades may be produced by using sulphuric or nitric acid in place of the sodium salt; and these may be varied again by using a barium salt with the lead acetate and potassium bichromate.

By using white lead, potassium bichromate, and caustic soda in certain proportions and boiling for a short time, a red of considerable brilliance is formed, which is known commercially under various names, such as Persian red, Victoria red, American vermilion, Chinese red, Derby red, chrome red, and several less familiar names.

The chrome-lead pigments are, almost without exception, very good pigments from the practical painter's standpoint. They have good covering powers, brilliancy, and permanency under ordinary conditions. They have the defects of all the other lead pigments, but their good qualities are so pronounced that, for yellow paints, they may be said to have scarcely any competing rivals for first place commercially.

The zinc chromes, while distinctly inferior to the lead chromes as pigments, are, nevertheless, important. The method of making them does not differ essentially from that of making the lead chromes, except that a zinc salt is used in place of a salt of lead. This salt is mixed in definite proportions, either with chromic acid, or with bichromate of soda, or potassium. The tints obtained from these mixtures are known severally in commerce as "marigold tint," "lemon tint," "pale tint," "zinc chrome," "deep chrome," etc. Most of these pigments have good color and body, and mix readily with other pigments.

Ranking next in importance to the chromes as yellow pigments, although usually considered distinctly inferior to them, are the natural mineral pigments, ochres and siennas. These substances are widely and abundantly distributed throughout the mineral world, although the quality of the product varies greatly in different regions. The color of the ochres is due to the presence of hydrated peroxide of iron; and while this substance gives the color to the siennas also, it is modified in these pigments by the presence of small quantities of manganese. With these substances there is always a mixture of various "earths," so that the pigment is a conglomerate mixture of several chemicals. Some of these mixtures occur in such natural deposits that they may be used as pigments of good quality without treatment other than that of grinding to a fine powder.

When ochres are heated they turn red, and are sometimes marketed as Venetian red, or Indian red. When the siennas are heated, however, a reddish-orange shade, known as burnt sienna, is produced. The cause of this change of color is probably the conversion of hydrated iron oxide to an anhydrous state; but as yet we do not know just why the ochres turn red, while the siennas have orange color during the process.

That the composition of ochres is complicated is shown by the following analysis of Oxford ochre, by Hurst:—

Water, hygroscopic	6.887	per cent.
Water, combined	8.150	"
Calcium oxide	0.998	"
Sulphur trioxide	1.321	"
Alumina	6.475	"
Ferric oxide	12.812	"
Silica	63.478	"
	100.121	

The siennas differ very little from the ochres in composition except for the addition of manganese. The quantity of this is so small, however, that it is only recognized as a "trace" by the chemists in the analysis, yet this "trace" is sufficient to alter the color.

An important pigment that is a favorite with some artists on account of its brilliancy, is cadmium yellow, which has the chemical formula CdS. It is permanent and is obtained in several shades of yellow and orange and mixes well with most other pigments.

Among the yellow mineral pigments that have largely been replaced by some of the foregoing, are the "Mars colors" which were sold in many shades under various names. These colors possess no advantage over the ochres, and have the disadvantage of costing more. Mention has been made above of how the lead pigments, "Turner's yellow" and "Naples yellow," have also yielded to the chromes. The same is true of "King's yellow," which is a bisulphite of mercury.

Aureolin, a pigment lacking permanency, is still in use. It is a double nitrate of potassium and cobalt, and was at one time very popular with artists.

SOME BRILLIANT BUT POISONOUS PIGMENTS

We have seen that the pigments made from lead are poisonous compounds which must be handled with caution, both in the process of manufacture and in the subsequent operations of painting. Far more poisonous than the lead pigments, however, are those made from the metal mercury, which is the essential constituent of the most brilliant of the mineral red pigments, vermilion. Indeed, it is an unfortunate fact that most of the permanent mineral pigments—the green of arsenic, the blue of the prussic-acid compounds, as well as the compounds of lead and mercury, are poisonous.

Chemically, vermilion is a mercuric sulphide, having the formula HgS. It is found in nature as cinnabar, and the selected pieces of this mineral are placed on the market as "mountain vermilion." This is usually an inferior pigment, however, most of the vermilion on the market being an artificial product.

There are two forms of the mercuric sulphide, a non-crystalline one, black in color, and the one of crystalline form, known as vermilion. Either one of these may be produced from the other by proper manipulation; and in practice the red sulphide is frequently made from the black.

Black sulphide may be made by the simple processes of stirring together equal parts of mercury and sulphur moistened with water, a mixture of mercury and ammonium sulphide, or by heating mercury and sulphur together. It is a velvety, black mass, which is changed into the crystalline sulphide, or vermilion, by heating to a temperature at which it volatilizes.

Chinese vermilion, which is superior in quality and shade to Western vermilions, is a mercury product prepared by some process unknown to Europeans. The alleged method of making it has been told many times, but the true method probably still remains a secret of the Orientals. It is a very expensive pigment; but so also are the Western vermilions, even the cheapest of which cost so much that there is constant temptation for dishonest manufacturers to adulterate them. Most of these adulterants are combinations of lead and iron pigments, some of which give a color closely simulating true mercury vermilion, but all of them lack the permanency and fineness of shade of the more expensive pigments.

A close rival of the mercury vermilion, in the matters of shade and permanency, is antimony vermilion, which is a trisulphide of antimony. Commercially, however, it cannot be considered a great rival, although it seems to have many qualities that would entitle it to such a place were it not for the established prejudice in favor of the older pigment. It is much less expensive than true vermilion, and this advantage seems to be gradually bringing it into favor with practical painters.

For several reasons the ferric-oxide reds, which are sold in the market under such names as Venetian red, Indian red, scarlet red, purple oxide, rouge, and several other less general names, are favorite pigments with painters. They are relatively cheap, permanent under all conditions, and when mixed with other pigments for the most part do not affect them and are not affected by them. They are found in a natural state, sometimes so pure and of such quality that the mineral may be powdered and used as a pigment without further treatment. This is not usually the case, however, and most of these pigments are manufactured artificially by one of the many processes known to chemist and paint-manufacturer.

Another red pigment that is a great favorite for many kinds of protective and decorative purposes, is red lead—a lead oxide having lead and oxygen in the molecule in proportion of three to four, Pb_3O_4. It is probable that these proportions are not quite as exact as in the indicated chemical formula, for, as we have seen, chemical formulas and colors do not always correspond; but this formula represents the composition very closely.

Red lead has good coloring and covering powers, and, under ordinary atmospheric conditions, is permanent. It has the defect of all the lead pigments of being affected by sulphuretted hydrogen, but under ordinary conditions this is so slight that it need not be considered. It has a powerful drying effect upon linseed oil, and this quality adds to its value for many purposes, such as packing the joints of steam-pipes.

Another form of red lead—a pigment having the same chemical composition as far as can be determined, although of different color—is orange lead. It is paler in color, and lighter in weight, and is made by a different process, but what may be the difference in the arrangement of the atoms in the molecules that makes a different shade still remains a mystery.

Among the other red mineral pigments which are of little practical importance, although, in some instances, of brilliant color, are the chromium salts of lead, mercury, copper, and silver. Most of them are lacking in permanency and are too costly for general use, although chrome lead is an exception, and will be referred to again in a moment.

The biniodide of mercury is also a brilliant color—"brilliant scarlet," it is called in the trade. It is very fugitive, however, and is only useful where a temporarily brilliant effect is desired. A very pale, although permanent, red is prepared from magnesia and nitrate of cobalt, but this pigment is not in general use.

GREEN MINERAL PIGMENTS

Of the green mineral pigments probably the most important for ordinary painting are the various shades of Brunswick green. Emerald green, the poisonous substance known as "Paris green" in America, which was once very popular as a pigment, and is still used by artists for their purposes, has now been replaced largely by a coal-tar product which will be referred to a little later. The true chrome green and other copper greens are also of considerable importance as pigments, and there are several others.

The so-called Brunswick greens formerly in use were compounds of copper; but these have now been completely supplanted by the more modern greens of the same name but of different compositions. The modern Brunswick greens, which are known commercially as "pale," "middle," "deep," "extra-deep," etc., are mixtures of barytes, Prussian blue, and chrome yellow, or compounds of similar chemicals in varying proportions. The relative amount of Prussian blue determines the shade of the green pigment, the larger the amount the deeper the shade. Thus one hundred parts of barytes, two parts of Prussian blue, and thirty-five parts of chrome yellow make a pale Brunswick green; whereas if the amount of Prussian blue is increased to eight parts, a very deep shade of Brunswick green is produced. Of course the quality and color of the Prussian blue and the chrome yellow have to be taken into consideration, but the general rule holds good in any case.

As pigments, the Brunswick greens work well either in oil or water. They have good covering power, and as they are permanent enough for all practical purposes, and mix well with most other pigments, they are favorites with practical painters.

The chrome greens, which are usually mixtures of oxides and phosphates of chromium, are very popular pigments with both artists and artisans, on account of their brilliance of color, permanence, and good mixing qualities. When mixed with other oil pigments they remain unchanged, and have no effect upon the other pigments; but as water-colors they change slightly in time. In the experiments conducted by Messrs G. Rowney & Company, of London, to determine the permanency of various colors, the specimen of chrome green mixed with flake white and exposed to sunlight for twelve months showed only the slightest change from the original shade.

There are several copper greens which at various times in the past have been important as pigments, but all of these have gradually ceased to be of importance to the painter. Of these verdigris, Scheele's green, and emerald (or Paris) green, form a group similar in composition, each one of which has had its period of popularity only to be supplanted by another pigment. Verdigris, an acetate of copper, is the oldest and poorest pigment of this group. It was supplanted as a pigment soon after 1778, when the Swedish chemist, Scheele, announced the discovery of the pigment that has since borne his name. This is a basic arsenite of copper, and although somewhat better as a pigment than the copper greens known before its discovery, it cannot be considered as a high-class pigment, and dropped out of use after the discovery of emerald green in 1814. This green is an aceto-arsenite of copper, and is very poisonous. It has good covering power, brilliant color, and in dry places is very permanent; but on account of the dangers attending its use it has fallen into disfavor as a pigment except with artists. This waning in popularity of emerald-green as a pigment for over half a century, has been offset by a corresponding increase in popularity of this substance as an insecticide. Thousands of bushels of vegetables are saved annually by the use of Paris green.

Of the other copper-green pigments, a basic carbonate known as "mineral green," or "malachite," occurs as a natural green mineral in several places on the earth. Green verditer is also a basic carbonate of copper which is made artificially, as is also Bremen green. But none of these substances need be considered seriously in the list of practical pigments in use to-day.

Terre verte, or Verona green, as it is sometimes called, is a natural green mineral pigment of very complex composition. It contains silica, ferrous oxide, potash, magnesia, and possibly alumina, soda, and manganese. It is very permanent as a pigment, and was used extensively by the ancient and medieval painters, who had no other permanent green pigment. It is poor in body and coloring, and has lost its former popularity since the discovery of so many other brilliant greens.

One of these brilliant greens is the compound of the oxides of zinc and cobalt, known as cobalt green. For commercial painting this pigment is too expensive, but as an artists' color it is very popular. It is permanent, not affected by mixing with other pigments, and has good covering power. On account of these qualities, numerous efforts have been made to find a cheap way of manufacturing it commercially, but so far these have been unsuccessful.

Besides these mineral greens there are others, such as zinc green, titanium green, manganese green, and Brighton green, that have been employed more or less extensively at different times, but are of relatively little importance at present. Zinc greens are made by mixing zinc chrome, Prussian blue, and barytes. Titanium green is a ferrocyanide of titanium which was made originally as a substitute for the arsenical greens, but is too expensive for practical purposes. Manganese green is essentially a manganate of barium, and is used very little as a pigment. Brighton green is a preparation of the basic acetate of lead.

BLUE PIGMENTS FROM THE MINERAL WORLD

Although the various shades and tints of blue are among the most important as colors, the number of blue mineral pigments is relatively small. Fortunately this deficiency in number is more than counterbalanced by the permanency of these pigments. The three most important are ultramarine, Prussian blue, and cobalt blue.

The pigment ultramarine, as used by the ancients, was literally "worth more than its weight in gold," as was said a few pages back. For this pigment was made by grinding to powder the semi-precious stone, lapis lazuli, found only in China, Siberia, and Persia. Its cost, therefore, placed it outside the realm of commercial pigments; and only the opulent among the artists could afford to use it. It was made by grinding the mineral to a fine powder, mixing this with a compound of resin, wax, and linseed oil, and kneading the mixture in a bag immersed in hot water. The blue color comes through the cloth into the water and finally settles. It is a tedious process of ancient origin, and yet no simpler or better method has ever been discovered for making the ultramarine pigment from the mineral.

Even if such a method had been discovered, the pigment would still have been far too expensive for general use, owing to the cost of lapis lazuli itself. But early in the nineteenth century, when the infant science of chemistry was doing so much to solve the hitherto elusive riddles of Nature, practical chemists effected the analysis of the mineral ultramarine with a view to its artificial production. The day of great triumphs of analytical and synthetic chemistry had just dawned, and one of the first was the production of an artificial ultramarine product superior in quality to the natural, and costing less than a thousandth part as much.

Analysis had shown ultramarine to be largely a compound of the common substances, silica, aluminum, lime, soda, sulphur—plebeian substances in themselves, that become of such regal importance when combined in the proportions to form the material ultramarine. And now the "Société d'Encouragement de France" offered a prize of six thousand francs to "anyone who would effect this combination synthetically, and produce ultramarine in wholesale quantities." This prize was soon won (in 1828) by the eminent French chemist, Guimet, who was able to make the pigment on a large scale at a very low price. The exact method used by Guimet was kept secret, and still remains so; but as his discovery was followed shortly by the discovery, by several other chemists, of processes leading to similar results, his precise method of procedure is of historical importance only.

At the present time there are two general methods of manufacture, each of which is subject to certain variations. In one of these a mixture of kaolin, soda, charcoal, quartz, resin, etc., is first calcined, forming a green substance known as ultramarine green. To convert this into blue ultramarine a second heating-process with sulphur is necessary. In the other method the process is completed in one heating, and as this also gives the better pigment, it is the one most generally used. Hurst describes one of these methods as follows:

"A very good mixture to use is—

Kaolin	76 parts
Sodium carbonate	60 "
Sodium sulphate	15 "
Sulphur	78 "
Charcoal	16 "
Diatomaceous earth	18 "
Quartz	10 "
Resin	12 "

"All these ingredients are ground together into a homogeneous mass; this is a point of great importance. The mixture is loosely packed into crucibles fitted with flat lids, which are luted on by means of mortar. When the mortar-luting is dry the crucibles are piled in ovens large enough to hold 400 to 500 crucibles. . . . After all the doors and openings into the oven are made up, it is fired to a bright-red heat for several hours, the length of time varying considerably and depending upon a number of factors such as the state of the weather, the composition of the mixture, etc. Experience is the only school in which the ultramarine-maker can learn how to regulate the time required.

"After the heating, all the apertures are carefully closed, so as to exclude air, and the furnace allowed to cool for four or five days; the oven is then opened, and the crucibles withdrawn and opened, the contents turned out, and the badly burnt pieces carefully separated; the good portions are ready to be finished.

"The changes which go on during the heating of the mixture are both curious and interesting. The mixture when first put into the crucibles is of a grayish color, but during the process of burning it passes through a series of color-changes—brown, green, blue, violet, red, and white. The brown appears with the blue flames, due to the burning of the sulphur; it is a fine chocolate-brown but is very unstable; on exposure to the air it enters into combustion. Many efforts have been made to preserve it, but these have been fruitless. The green, which is the next change, begins to form when the sulphur has ceased to burn; like the brown it is unstable, as the substance burns on exposure to the air. Following the green comes the blue, which is formed when the temperature has reached about 700° C., or a bright-red heat; when the temperature gets higher the color changes to a violet. With still higher temperatures, first a red, then a white variety is formed. These changes are due to oxidation; when the white ultramarine is heated with reducing agents, such as carbon, the colors are re-formed in the reverse order to that in which they first appeared."

The ultramarine as it comes from the furnace must be "finished" by grinding, and there are other manipulations subordinate to the process described. The essential thing is that it is possible now to make this most useful pigment for such a small amount that it is one of the cheapest of painters' colors.

A blue pigment that is a close rival of ultramarine is Prussian blue (known also as Berlin blue, or Chinese blue) which is a ferric ferrocyanide—a complex compound of iron, carbon, and nitrogen, the last two elements combined in the form of the radical known as cyanogen. It was discovered accidentally by the Prussian color-maker, Diesbach, early in the nineteenth century. Diesbach was engaged in the manufacture of a red lake pigment, when, happening to use an alkaline solution which had been employed in some treatment of ox blood, he found that quite by chance he had produced a beautiful blue pigment. Following up this accidental discovery, he soon was able to produce the pigment, Prussian blue, and place it upon the market in any desired quantities. Other color-makers took up the problem at once and soon solved it by various methods, so that this color took its place beside ultramarine as a regular commercial product.

Very fine grades of Prussian blue are frequently designated as "Chinese blue," and may be made in the following manner:—

One hundred parts of sulphate of iron are dissolved in cold water and ten parts of sulphuric acid added to the solution. This solution is then mixed with a solution of one hundred parts of yellow prussiate of potash. As a result, a bluish-white precipitate is formed, which settles to the bottom of the vat. To this precipitate a mixture of about twenty parts of bleaching-powder and water is added, and thoroughly stirred, after which a little hydrochloric acid is poured in, on the addition of which the characteristic blue color gradually develops. This blue pigment settles to the bottom in a thick mass from which the overlying liquid is run off. It is then washed, drained, and finally pressed into pans and dried in dark ovens at a temperature not higher than 130° F. This is, of course, only one of the many methods of manufacture, but it may be taken as a characteristic one.

The Prussian blues have a characteristic greenish-blue tint not seen in any other pigment. They are permanent as oil-colors, and their coloring power is remarkable, one part of Prussian blue giving a distinctly blue color to six hundred parts of white lead. When used as a water-color Prussian blue has the peculiarity of fading considerably when exposed to light for any length of time, but of recovering its original shade when placed in the dark.

Cobalt blue, the third important blue mineral pigment, is known commercially in two forms, "smalt," and cobalt blue. Smalt is really a glass colored by cobalt, and is a very old pigment. In recent years its popularity as a pigment has declined as it is inferior to artificial ultramarine.

True cobalt blue is a favorite color with artists, particularly with those who work in water-colors, on account of its permanency and mixing qualities. It is a compound of the oxides of aluminum and cobalt, with an occasional trace of phosphoric acid. It may be made in various ways, perhaps the best method being that of dissolving nitrate of cobalt in water, and to this solution adding sufficient sodium phosphate to precipitate the cobalt as phosphate of cobalt. After this precipitate is washed with water it is mixed with a precipitate of alum and sodium carbonate in the proportion of one part cobalt to eight parts aluminum. This is then heated to a red heat and kept at that temperature until the blue color is fully developed, the process requiring from one-half to three-quarters of an hour.

The three blue pigments just described—ultramarine, Prussian blue, and cobalt blue—have practically displaced all the older blue metallic pigments, such as those made from copper. Such pigments as mountain blue, Bremen blue, blue verditer, which are all compounds of copper; and lime blue, which is a mixture of copper hydroxide and calcium sulphate, are now of interest historically only. But of far greater interest in this respect is the pigment "cæruleum"—the blue pigment used by the Egyptians, which has resisted the action of time and the elements for several thousand years in many known instances. It is this blue pigment that may still be seen in the ruins of Pompeii, Cairo, and Alexandria; but it is only within the last quarter of a century that its chemical composition has been known. Fouqué, the French chemist, found it to be—

Silica (SiO_2)	63.7 per cent.
Calcium oxide (CaO)	14.3 "
Copper oxide (CuO)	21.3 "
Ferric oxide (Fe_2O_3)	0.6 "

It is therefore, probably, a double silicate of copper and calcium, and Fouqué believes that the ancients made it by fusing together roasted copper ore with lime and sand.

THE BROWN MINERAL PIGMENTS

The brown mineral pigments, constituting a small but important group, are mostly natural pigments. The most important of these is umber, a substance closely resembling the ochres and siennas, but containing more manganese, which is probably the cause of the darker color. The umbers vary in hue from violet brown to reddish brown, and are found in thick mineral deposits in strata sometimes thirty feet in depth. They are found in almost every country, but the finest comes from Cyprus.

Commercially, umber is marketed in lumps, just as it comes from the mines, or in a powder, which is simply the natural product, ground and levigated. Burnt umber, which has a darker and warmer color than the raw mineral, is made by heating the natural umber to a red heat.

Chemically, umber is a very complex substance, specimens from different sources showing considerable variation in this respect. Among its components are silica, manganese, aluminum, calcium carbonate, ferric oxide, and barium sulphate. The color of umber is permanent; it mixes well with other pigments, and for these reasons, and because of its cheapness, it is a favorite with painters and artists.

Vandyke brown is a pigment made from several natural deposits, some of them of peaty origin, and named after the great Dutch painter on account of his fondness for brown colors. It is also manufactured from the cuttings of cork that have been calcined. The common Vandyke browns for sale in the market are usually mixtures of some black pigment, such as lampblack, with red oxide of lead and yellow ochre. They are good pigments, however, mixing well with other colors, and being practically permanent under all conditions.

PIGMENTS FROM VEGETABLE AND ANIMAL SOURCES

Generally speaking, it may be said that the pigments from animal and vegetable sources are of greater importance than those of mineral origin to the dyer, while to the painter the reverse is the case, although there are certain pigments from every source of great importance to both. But even substances of purely organic nature, when used as pigments are usually combined with some metallic substance. Thus, the important class of pigments known as the "lakes" are compounds of an organic coloring-principle with a metallic body.

The lakes seem to derive their name from the ancient Italian dyers, who called the colored scum which rose to the surface of their dye-vats, *lacca*. This they gathered and sold to artists as a pigment, which came to be known eventually as "lake" pigment.

Until recent years the organic coloring-principle of the lake pigments was derived from cochineal insects, madder red, Persian berries, Brazil wood, sapan wood, fustic, and several other sources; and these sources continue to be of importance to-day. But the discovery of the products of coal-tar revealed, among other things, that all manner of lake colors could be made from that peculiar substance; and as a result the animal and vegetable worlds have been largely shorn of their importance as the source of pigments. Indeed, it seems so certain that the pigments from animal and vegetable sources will eventually be replaced by those derived from coal-tar, and similar mineral products, that a description of the method in use to-day of making a vegetable pigment may have only historical importance and interest to-morrow.

Aside from white pigments, there is no shade or color that cannot be made from the lakes. Some of these are fugitive and of little use as permanent pigments, while others, such as carmine, make the "finest and most expensive colors used in painting." Since there is such an array of these colors, many of which have been named and renamed many times, it is obviously impossible to consider each in detail, and a description of a few of the most important will suffice for our purpose here.

The original source of the finest of all pigments, carmine, was the North American continent, although the cultivation of the cochineal insect, from which the color is derived, has now extended to all tropical countries. When the soldiers of Cortez first invaded the Aztec empire in Mexico, they found the natives using a brilliant, red dye obtained from insects that were parasitic upon certain cactus plants. Only the female insect is used for coloring-material, the males being much smaller and fewer in number. The female insects cling to the cactus leaves in enormous numbers, from which they are brushed onto heated metal plates, and killed.

These insects contain as high as fifty per cent. of the coloring-matter called carmine, which is the same name given to the lake made from it. It is obtained by reducing the dried insects to a pulp, and afterward macerating them in water. The coloring-matter is then precipitated with an aluminum salt, great care being taken to have all the materials used perfectly pure, as any impurities affect the shade. Thus the impurities contained in ordinary water, or even the minerals in spring water, may injure the color if such waters are used. It is customary, therefore, to use distilled water in the process of manufacture. And the same care that is taken in selecting the water is applied to all the other substances used. For it has been demonstrated many times that herein lies the secret of making fine carmine pigment; whereas it was supposed for many years that some special and obscure process was necessary.

Carmine, besides being the most brilliant and beautiful red color known, has the advantage over most of the other reds of being non-poisonous. It can be used for coloring foods, and is used extensively in tinting confectionery and various preserved fruits.

Practically the only drawback to the use of carmine in almost every field where bright colors of the paler tints of red are used, is its cost. It has never been possible, even in the vast territories of the tropics where the little cochineal insects flourish, to produce them in sufficient quantity to supply the demand for their coloring-matter. Consequently the price of carmine has always been very high. But all this is now changing. The pale workers of the laboratory have found a means of doing what the bronzed men of the fields could never accomplish. They have found a way of supplying unlimited quantities of an artificial carmine, made from coal-tar, at a mere fraction of the cost of the older product—a synthetic carmine, quite as good as the natural pigment. So after centuries of useful bondage in the service of savage and civilized man, the little Mexican insect seems to be serving the last years of its usefulness, and will very shortly be allowed to run the course of its natural life like other more fortunate tropical insects. A few more years must pass before the artificial carmine will completely supplant the cochineal product; but this substitution seems now absolutely assured.

Such substitution is taking place, or has taken place, in the case of the other animal pigments, which need be mentioned here only for their historical interest.

Lac-dye, once a favorite pigment material, is obtained from an insect not unlike the cochineal. The same is true of alkermes from which the famous Venetian scarlet was made. It comes from an insect found in Persia, Morocco, and Algeria. Purree, or Indian yellow, is manufactured in Bengal from the urine of cows fed on the leaves of the mango tree. Sepia, a favorite pigment of water-color artists, is made from the gland of a marine cephalopod, known as the "ink-fish"; while "mummy," an inferior yellow pigment at one time fancied by some artists, is made by the action of such solvents as chloroform or benzine on Egyptian mummies.

The vegetable coloring-matters, like the animal, are of rapidly declining importance, as practically every one of them can now be made cheaper artificially than they can be obtained from natural sources. This means that certain great industries have been created at the expense of other older ones. Painters and dyers now look to city workshops for their supply of pigments that formerly came from the fields.

Perhaps the most conspicuous example of the revolutionary effect of the introduction of coal-tar colors produced synthetically, is that of the complete elimination of madder-root as a source of color-material. Madder, known botanically as *Rubia tinctorum*, was cultivated extensively until recently, in many countries, for its roots, from which some of the most important lake pigments were made. The principal coloring-matter of madder was alizarine, from which a permanent red, and several other colors, invaluable for dyeing fabrics and making pigments for painting, were obtained. But alizarine is now made from coal-tar at a cost so much less than it is possible to produce the natural color-material, that the madder-growers have been obliged to plant their fields with grain and forego their time-honored vocation.

The struggle of the madder-growers against the encroachment of the new, laboratory-made product that was destined to engulf their industry, is a tragic page in the history of scientific advancement and commercial progress. English scientists had been foremost in producing colors from coal-tar; and as a result the establishment of great manufacturing plants for making them were in progress. The increase of the madder industry of such establishments became apparent; and so great was the influence of the madder-growers, that laws were enacted for protecting the older industry and curtailing the new. For the moment these laws proved effective; but only for the moment. Laws made for the benefit of the few and against the interests of the many cannot be long effective. The English artificial-color manufacturers, who were then leading the world, were ruined, but the manufacture of artificial colors crossed the Channel to France and Germany, and the madder-growers soon found themselves unable to compete with the foreign artificial colors which now flooded the market. Before the restrictive legislation against home manufacture could be repealed, the French and German color-makers had gained a lead which the English manufacturers have never been able to overcome.

This legislation against alizarine manufacture was a repetition of somewhat similar legislation in several countries, a few centuries earlier, to prevent the importation of indigo, long known to the East, but just then becoming known in Europe. Its brilliant color took the fancy of the wearers of colored silks as a satisfactory change from the prevailing reds and yellows which were the popular dyes of the time. The cultivation of the woad plant, and its manufacture into a yellow dye, constituted an enormous industry in many European countries, particularly Germany and England. The introduction of the strikingly beautiful dye, indigo, menaced every branch of this industry, and such pressure was brought to bear upon the legislators that stringent laws were passed forbidding the use of indigo for dyeing purposes. In the "free" city of Nuremberg, the crime of dyeing a fabric with indigo was, until the beginning of the eighteenth century, punishable with death.

This famous dye is obtained from a plant that flourishes in the tropical regions of both hemispheres, the species *Indigofera tinctoria* being native to India, while *Indigofera anil* is the species of Central America and the West Indies. The dye-stuff is obtained from the plants by causing them to decompose in water. The pigmentary matter settles as a blue deposit, which is collected and carefully dried.

Just at the present time the same element that stopped the raising of madder is stopping the importation of indigo into Europe and every other civilized land, more effectually than legislation could ever do. Germany has perfected methods of manufacturing from coal-tar an indigo that swiftly and surely is replacing the natural product.

In point of age indigo is one of the oldest known colors. The Egyptians used it sometimes to color the wrappings of their mummies, and the fact that these wrappings still show the blue color attests the permanency of the pigment. The younger Pliny in his *Natural History* gives a very exact description of indigo, and some tests for detecting it. Among other things he mentions that when heated over a fire it "burns with a purple flame and gives off a smell of tea."

Until the opening years of the present century, artificial indigo was not able to compete with the natural product, about five thousand tons of which were used annually. But German manufacturers were perfecting methods, and in 1908 about one-fourth of the indigo used was of artificial manufacture. This leaves little room for doubt that it will be only a matter of a few years before the indigo-growers of the world will be obliged to devote their fields and energies to growing some other crop, probably less profitable.

Logwood, the wood of *Hæmatoxylon campechianum*, from which red, blue, violet, and black colors can be obtained, is another important New-World contribution which the Spaniards discovered in South America. For four centuries it was one of the most important of dyestuffs, but, like indigo, it is now being rapidly displaced by the artificial colors. The other vegetable coloring-materials, such as chlorophyl, dragon's blood, fustic, Persian berries, Brazil wood, gamboge, tumeric, litmus, redwood, and saffron have now been relegated to a place of historic interest only, so far as the commercial pigment- and color-maker is concerned.

THE COAL-TAR COLORS

The story of the discovery that the black, oily refuse of coal used in the manufacture of gas could be converted into coloring-material of every known shade and hue forms one of the most picturesque romances of applied science.

Thousands of centuries before man came upon the earth, in that particular period of the world's development known as the Carboniferous Age, there flourished everywhere in the hot, moist air luxuriant, gaudily colored vegetation. The huge animals and reptiles that wandered among the flowering trees and plants trampled them under foot in the mire, and the natural destruction of time and the elements piled them in constantly deepening layers upon the ground, where all the beauty they once represented was lost in the dirt and grime of their decaying surroundings. Succeeding ages piled layers of stone over this stratum of decayed vegetation, burying it and compressing it into the stonelike substance that we know as coal.

Seemingly, Nature had destroyed her creation of life and color, and had hidden every trace of her handiwork. But Nature does not create and destroy indiscriminately.

The heat represented in its latent form in the growing plants, and the light transformed into their brilliant colors, were locked within the lumps of coal ready to be produced actively whenever man should have found the way to do so. It took him all but the last two centuries to discover the relatively obvious fact that the heat could be extracted from this coal; and all but the last half of the last century to unravel the complicated process of restoring the colors buried, and apparently lost, so many centuries before. That he has done so in scores of instances is one of the greatest triumphs of modern chemistry. What other achievement of man savors so much of the miraculous as this creation of hundreds of attractive colors and tints from this repulsive black refuse of grimy coal-heaps?

The conquest had its beginning in 1826 when Unverdorben discovered aniline among the products of the dry distillation of indigo; and when Runge eight years later proved the existence of the same substance in coal-tar. The first aniline color was not produced, however, until 1856, when the English chemist, Perkin, produced "Perkin's violet." But this discovery was somewhat in the nature of an "accident," scientifically speaking, and the color could not be produced as a commercial commodity. It required Kekule's promulgation of the theoretical constitution of benzine, in 1867, to give the chemists a basis for accurate synthetic work. Until this time the discoveries had been empiric in character; but now the scientific production of colors, of greater or less value commercially, followed very rapidly. The most revolutionary discovery came in

1868, when Graebe and Liebermann effected the synthesis of alizarine, which proved the death knell to the madder industry. Ten years later Baeyer produced indigo commercially—the beginning of the downfall of the natural product. Since then important practical discoveries have followed each other with bewildering rapidity. Something like four hundred coal-tar colors are now in use for the manufacture of lakes; and the end is not yet.

The amount of coal-tar available in ordinary coal is relatively small, the proportion being about one to twenty. But in the aggregate this amount suffices to supply the demand. The coal-tar colors on the market are usually in the form of a powder or crystals, the shade of which may be quite different from the solution. All of them are very complex chemical compounds, many of which, although identical in the number and kind of atoms in their molecules, are very different in color. The explanation of this seems to be in the arrangement of the atoms rather than in their number in each molecule, but the exact nature of this peculiarity has not been determined as yet. After all, it is no more wonderful or difficult to understand that two substances, each having six atoms of hydrogen and seven atoms of carbon in each molecule, should, let us say, be blue and red respectively, than, to take a familiar example, that the chemically identical substances, charcoal and diamond, should be, one colorless and the other jet-black.

The color-maker's interest in these coal-tar colors lies in their application to making lake pigments. In this process there is a very distinct and definite chemical action, which the manufacturer can produce with unfailing certainty; and yet "the theory of the formation of lake pigments has not been clearly enunciated." In many lakes there is this distinct chemical action, but not chemical combination. The salts used cause precipitation, but not in the definite proportions that would result from chemical combination. Variation in the relative amounts of the color and the salt causes variation in shade and color; but as this variation is constant, it is a concern of the chemist rather than of the practical manufacturer to determine the exact chemical action.

Many colors are produced by the combined precipitation of several salts and colors; and since so many colors are now known, the possibilities of combined precipitation are practically without limit.

DYES

While the various artificial colors, such as those made from coal-tar and those synthesized from other substances, are gradually revolutionizing the use of pigments in all fields where colors are used, a similar revolution has already been effected in the field of dyeing fabrics. Natural coloring-matters, such as cudbear and logwood, which were formerly among the mainstays of the dyers, are now seldom used. For the artificial colors not only give a wider range of colors and shades, but are cheaper, and very much easier to use. It was as dyes, rather than as pigments for painting, that they were first introduced; and while their application as dyes differs from their use as paints and stains, their composition is identical.

Without regard to the natural scientific grouping of artificial colors, the dyer divides them into six or more groups based upon their practical application. A recent grouping by Farrell is as follows:—

1. Direct or substantive cotton dyestuffs
2. Acid dyestuffs
3. Basic or tannic-acid dyestuffs
4. Mordant dyestuffs
5. Vat dyestuffs
6. Developed dyes

The first of these, direct or substantive cotton dyestuffs, are probably the most important to the dyer, as most of the colors are azo compounds, and dye vegetable fibers direct from an aqueous bath, with the addition of some such salt as sodium chloride. Some of them are also adapted to dyeing such animal fibers as wool and silk, and the shades are usually very fast.

The second of these, the acid dyestuffs, are the sodium salts of sulphonic acids and the nitro-colors. These are particularly useful in dyeing animal fibers.

The third, or basic dyestuffs, are substantive to wool and silk fibers, but may also be used to dye vegetable fibers. They are not very fast colors, however, and are not used very generally.

The fourth, mordant dyes, are little used on account of the difficulty of applying them. The one color for which they are used extensively is Turkey-red on cotton textures, the color being produced from alizarine and an alumina lime and fatty-acid mordant.

Vat dyes, or the fifth group, are difficult to apply, but they include the important dyestuff, indigo.

The sixth group, or developed dyes, are produced in the fibers from the substances that are not dyestuffs. In this group come the important aniline black, and the colors produced by the combination of naphthols with the diazotized amido compounds.

The number of these artificial dyes runs into the hundreds, and there are endless methods of applying them. As the composition of many of the colors and the methods of applying them are trade secrets, it is impossible to consider them individually, or to treat the subject in anything but the most general way.

VARNISHES

By all means the most important varnish—indeed, the only one known to most persons by that name—is the commonplace substance used as finishing for furniture, vehicles, interiors of houses, and a hundred other every-day things. To be sure there are several other rather common varnishes, such as damar varnish, which is made of a resin dissolved in an essential oil, and spirit varnish, of which shellac varnish is the most familiar example. But the importance of these is insignificant as compared with that of what is familiarly known as "varnish," without any distinguishing adjective, and which is a solution of resin in linseed oil, thinned to a certain consistency with turpentine or benzine.

The process of making varnish constitutes a great industry in itself, and even varnish of very high quality is made in large quantities in such factories. The apparatus for manufacturing is very simple, consisting essentially of a large copper kettle mounted on wheels for convenience in handling, and a chimney with a kind of hooded fireplace at its base. The fireplace serves for heating the contents of the kettle, while the chimney carries off the dangerous fumes and smoke. The copper kettle has a closely fitting cover, with an opening through which a stirring-rod may be inserted—an arrangement that has been in vogue for at least a thousand years.

The first step in the manufacture of varnish is the melting of the resin. Lumps of this substance are placed in the copper kettle and run under the hood over the fire. As the resin melts it gives off a pungent and highly inflammable vapor, which is conducted off through the chimney by means of the opening in the cover of the kettle to which a pipe is attached. As the heat in the kettle increases and the lumps disappear, the liquid resin tends to foam, this tendency being controlled ordinarily by vigorous use of the stirring-rod. If the heat is so intense, however, that boiling-over is imminent, the kettle is pulled quickly out of the fireplace and allowed to cool a little. It is to meet such an emergency that the varnish kettles are mounted on wheels.

During the melting-process from ten to twenty-five per cent., by weight, of the resin is driven off in the form of vapor. The temperature of the liquid resin rises to at least 650° F. by the time the mass is completely melted. But both these things vary greatly in different resins. And it is not a common practice among varnish-makers to determine the stage of melting by the use of thermometers (as is done in experiments on a small scale in the laboratories) but to depend upon the "feeling" by means of the stirring-rod in the hands of an experienced workman.

When the resin is dissolved, the kettle is withdrawn from the fire and allowed to cool a little, and the foam to settle. Meanwhile the requisite amount of linseed oil is being prepared in another kettle. This preparation consists in heating it to a temperature varying between 100° F. and 500° F. according to the quantity, quality of varnish to be made, and individual preference of the manufacturer. The oil is added to the melted resin, the mixture being stirred constantly during the process. To all appearances a perfect solution results; but this is only apparent. If the mass were allowed to cool at this stage there would be a separation of the resin from the oil, and a cloudy mixture would result. Therefore the whole mass must be placed over the fire again, and heated until a drop placed upon a piece of glass no longer shows a cloudy appearance on cooling. In practice the manufacturer no longer depends upon this test, but is guided by the reading of a thermometer, keeping the mixture at a certain temperature for a period of time that experience has taught him is right for making the particular quality of varnish in hand.

The immediate effect of the cooking, besides the essential one of causing the two substances to form a solution, is to thicken the liquid—to make it so viscid that it will require some thinner liquid, such as turpentine, to make it ready for commercial purposes. Both undercooking and overcooking are likely to be harmful to the finished product. Undercooked varnish, in which the resin and oil have not combined thoroughly, is likely to disintegrate quickly when applied to a surface exposed to air and light. Overcooked varnish is likely to be darker in color and requires more turpentine for thinning. As this evaporates when the varnish is applied, it leaves a thinner permanent covering, and affords less protection.

The final process of varnish manufacture is that of adding the requisite amount of turpentine to the oil-and-resin solution. This amount has been accurately determined beforehand, and when the liquid in the kettle has cooled sufficiently it is added slowly with constant stirring. If this is done in the neighborhood of a flame, conflagrations are likely to occur, as the heat from the contents of the kettle volatilizes a certain amount of the turpentine, which is very inflammable. Carelessness in this matter is a not unusual source of conflagrations in varnish-making establishments.

Benzine serves the same purpose in thinning varnish as turpentine, and as its cost is only about one-fifth that of the turpentine, it is used in cheap varnishes. It is very much more volatile than turpentine, and this is a disadvantage where fine work is desired. For this evaporation is so rapid that the varnish "sets" almost immediately, before the ridges left by the brush have time to be obliterated by the spreading and equalizing process as in the case of the slower-drying turpentine varnish.

The quality of the finished product depends upon three things—the care in making, the quantity of the ingredients, and their quality. It is needless to say that the best varnish cannot be made except from carefully selected resins, carefully prepared and refined oil, and highly refined turpentine. Everything else being equal, the relative amounts of these substances determine the kind, rather than the quality of the varnish.

The best representative of the spirit varnishes, and the one used preeminently in commerce, is shellac varnish. It is simply shellac resin dissolved in alcohol —a process requiring no heat, and no manipulation, although stirring hastens the process. The proportion of alcohol to the resin varies within wide limits, but in this country the usual proportion is about one part resin to one and a half parts alcohol. In this mixture there is not a complete solution of all parts of the shellac resin, as a waxy substance seems to be held in suspension.

When a thin layer of shellac varnish is spread over a surface the alcohol evaporates almost immediately, leaving a thin, impervious film of shellac resin and wax. On account of this quick-drying quality shellac varnish is most convenient for any purpose. The drying takes place so rapidly that several coats may be applied in a very short time; but curiously enough, if too many coats are applied at short intervals, a thick, rubbery film is formed that does not harden completely even after a long time. It is good practice, therefore, not to apply more than two or three coats without allowing some little interval for drying.

Damar varnish, the type of varnish made by dissolving a resin in an essential oil, is a solution of damar resin in turpentine. As in the case of shellac varnish, the resin is not completely dissolved, and the solution is accomplished without the aid of heat. Such a varnish never becomes very hard, and is not very durable. The film left by damar varnish is not simply a thin layer, but a combination of the damar resin and the residue always left by turpentine on evaporation. In this respect it differs from the spirit varnishes, in which the alcoholic solvent evaporates completely, leaving the original resin as the covering film.

These three kinds of varnishes just described may be taken as the predominating types of varnishes in general use. But the number of modifications and combinations of these, their mixtures with paints and stains, and their use in secret formulas of proprietary mixtures, which are placed on the market under many scores of names, is endless. Thus the "japans," which are numbered by dozens, are various combinations of varnishes and driers; while lacquers, enamels, etc., are various combinations adapted to special purposes. To go into details about even the most important of these substances would require volumes; and even then the treatment would not be complete, since so many of them are patented trade-secrets, not available for publication. It suffices fully for our present purpose, however, to give a concise idea of the principal substances used as bases for these combinations.

APPENDIX

REFERENCE LIST AND NOTES

CHAPTER I

THE DEVELOPMENT OF THE TELEGRAPH

In connection with this chapter the reader may advantageously consult any or all of the chapters in earlier volumes dealing with the development of electricity. The index will serve as a ready guide. There is also a reference list on the subject given in the Appendix to volume VI. under chapter VIII., "The Smallest Workers" (vol. VI., p. 324). Chapter VIII. itself, in vol. VI. (p. 148, *seq.*), will be particularly useful as dealing with the theories of electrical action.

(p. 4). The full account of Stephen Gray's discoveries in connection with conduction and insulation of currents will be found in vol. II., p. 262 *seq.*

(pp. 5–8). An anonymous communication suggesting the use of electricity for the purposes of telegraphy appeared, as stated in the text, in *Scot's Magazine* for February 17, 1753.

(p. 11). The story of the discovery of the galvanic or voltaic battery is told in vol. III., p. 229 *seq.*

(p. 14). Electro-magnetism gives new clues. The discoveries of Oersted and Faraday are recorded in vol. III., p. 236 *seq.*

(pp. 21, 22). Dr. Jackson's alleged connection with Morse's discovery. The quotation is from *The History and Progress of the Electric Telegraph*, by Robert Sabine, C.E., New York, 1869, pp. 32–33.

CHAPTER II

THE SUBMARINE CABLE

(p. 40). Enthusiasm over the successful laying of the cable. The quotation is from *The Times*, London, August 6, 1858.

CHAPTER III

WIRELESS TELEGRAPHY

(pp. 62, 63). Marconi on the tuning of wireless messages. The quotation is from an article by Marconi in the *Century Magazine* for March, 1902.

CHAPTER IV

THE DEVELOPMENT OF THE TELEPHONE

(p. 68). Dr. Robert Hooke's account of his telephone was communicated to the Royal Society in 1667.

(pp. 73, 74). Lord Kelvin's account of Elisha Gray's electric telegraph and Dr. Graham Bell's telephone is quoted from the *Report of the British Association for the Advancement of Science* for 1876.

(p. 74 *seq*). Dr. Graham Bell's account of his invention of the telephone is taken from a lecture on "Researches in Electric Telephony" given by Dr. Bell before the Society of Telegraph Engineers, October 31, 1877.

(p. 91). Wireless Telephony. The quotation is from an article entitled "The Latest Conquest of Space," by Beatrice Cassell, in *Harper's Weekly* for July 17, 1909.

Somewhat more technical accounts of various apparatuses connected with telegraphy and telephony will be found in the Key and Index Volume in the section devoted to Mechanical Instruments and Appliances.

CHAPTER V

THE EDISON PHONOGRAPH

(pp. 97, 98). Mr. Edison's description of the phonograph is quoted from *The North American Review* for May–June, 1878.

For a somewhat more technical description of the phonograph and also for a description of the magnetic phonograph, known as the telegraphone, see the Key and Index Volume.

APPENDIX

CHAPTER VI

PRIMITIVE BOOKS

A full account of the various types of ancient books with numerous fac-simile reproductions in tone and color may be found in Dr. Henry Smith Williams' *History of the Art of Writing*, New York and London, 1902–1903.

CHAPTER VII

THE PRINTING AND MAKING OF MODERN BOOKS

Much of the material for this chapter is taken from *A Short History of the Printing Press*, by Mr. Robert Hoe. Mr. Hoe is undoubtedly one of the highest authorities on the subject and he has treated it fairly and without prejudice. The reader who desires further information may advantageously consult this book.

(p. 131 *seq.*). A modern newspaper press. The quotation is from the *New York Herald* of May 10, 1891.

(p. 135 *seq.*). The account of a perfected magazine press is from an article in the *Century Magazine*, by Mr. Theo. L. DeVinne.

(pp. 142 *seq.*, 149, 151–152, and 155 *seq.*). The descriptions of linotype and monotype machines here quoted are from the article on printing, by William R. Rossiter, in the *Twelfth Census Report* of the United States.

CHAPTER VIII

THE MANUFACTURE OF PAPER

(p. 170). The force exerted by contracting paper. The quotation is from *The Story of Paper-Making*, by Frank O. Butler, Chicago, 1901.

(pp. 173–175). Paper from wood-pulp. Quoted from the article *Pulp and Paper*, by Charles W. Rantoul, Jr., in the *Twelfth Census Report* of the United States.

(pp. 180, 181). Car wheels from paper. Quoted from *The Story of Paper-Making*, by Frank O. Butler, Chicago, 1901.

CHAPTER X

PHOTOGRAPHY IN ITS SCIENTIFIC ASPECTS

The chapters on chemistry in vol. IV. may advantageously be read in connection with this chapter.

(p. 235). *The Photography of Color*, by Chapman Jones, in *Science Progress*, 1908.

(p. 241). From an address by Dr. C. E. Kenneth Mees before the London Society of Arts.

(p. 242). From the address of Dr. Mees noted above.

(p. 244). Scientific American Supplement, June 5, 1909.

(p. 246). From an article by Friedrich Lummers in the *Zeitschrift für Augeswandte Chemie*, 1909.

(p.246). From an article in *La Nature*, 1906.

(p. 248). This, together with several shorter quotations in regard to color photography, is from Mr. Jones' account of the subject in *Science Progress*, 1908.

CHAPTER XI

PAINTS, DYES, AND VARNISHES

A review of chapters on chemistry in vol. IV. will be of obvious service in connection with the subject-matter of the present chapter.

(pp. 297–299). The quotation is from *Painters' Colours, Oils, and Varnishes*, by Geo. H. Hurst, London, 1906, a work which has been drawn upon for much valuable matter elsewhere in this chapter.